GHENT UNIVERSITY

RECONNECT

D1.1 REPORT ON THE RESULTS OF THE RESEARCH CLUSTER ON EU-CHINA RESEARCH COOPERATION (CO-PATENT/CO-PUBLICATION ANALYSIS)

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Description	The present deliverable deals with EU-China cooperation in the science, technology and innovation sector. In order to assess the size of this cooperation, a twofold analysis working with big data has been conducted. One the one hand, entries on scientific publications indexed in the scholarly database Web of Science allow to filter for jointly written scientific publications between Higher Education institutions from the EU-27/AC (despite only the UK having formally associated to Horizon Europe at the time of finalising this report, we also included Norway and Switzerland under the term "Associated Countries", given their strong role in the European R&I system) and their Chinese counterparts (period 2011-2022). On the other, we use patent records available in the European Patent's Office PATSTAT database to extract joint patent applications and/or filings between legal entities (companies) in the EU-27/AC and China (period 2011-2022). In conjunction, these analyses cater to the needs of a growing European demand to understand China's involvement in science, technology and innovation cooperation with European actors better. At the same time, the empirical findings discussed in this report may be conducive to national and European R&I policy makers alike, given the on-going debate on how to address research cooperation with China in the future in the light of mounting concerns about security risks, the disregard for research integrity and the misuse of civilian research for military purposes (dual use).
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Version 1.0	Final version created by ZSI (11.09.2023)

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
BRI	Belt and Road Initiative
CAS	Chinese Academy of Sciences
EPO	European Patent Office
IPC	International Patent Classification
OECD	Organisation for Economic Cooperation and Development
PCT	Patent Cooperation Treaty
WIPO	World Intellectual Property Organisation
WoS	Web of Science

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1 EXECUTIVE SUMMARY

This report is an integral component of ReConnect China's WP1 initiative on science and technology, aiming to shed light on China's scientific and technological advancements. Specifically, the study delves into China's cooperation with the EU-27/AC[1] in the realms of science, technology, and innovation.

Employing the Web of Science and PATSTAT databases, we undertook an exhaustive bibliometric analysis. A refined set of keywords, targeting core areas like AI, machine learning, and big data, facilitated the exploration of extensive co-publication data. Our methodology involved data extraction, processing, normalisation, categorisation, and subsequent analysis on both the co-publication and co-patent analysis. The Science Metrix Ontology was instrumental in classifying scientific areas into three levels: Domain, Field, and Sub-field, providing granular insight into collaborations across different scientific fields under the co-publication analysis.

Some of the key findings include:

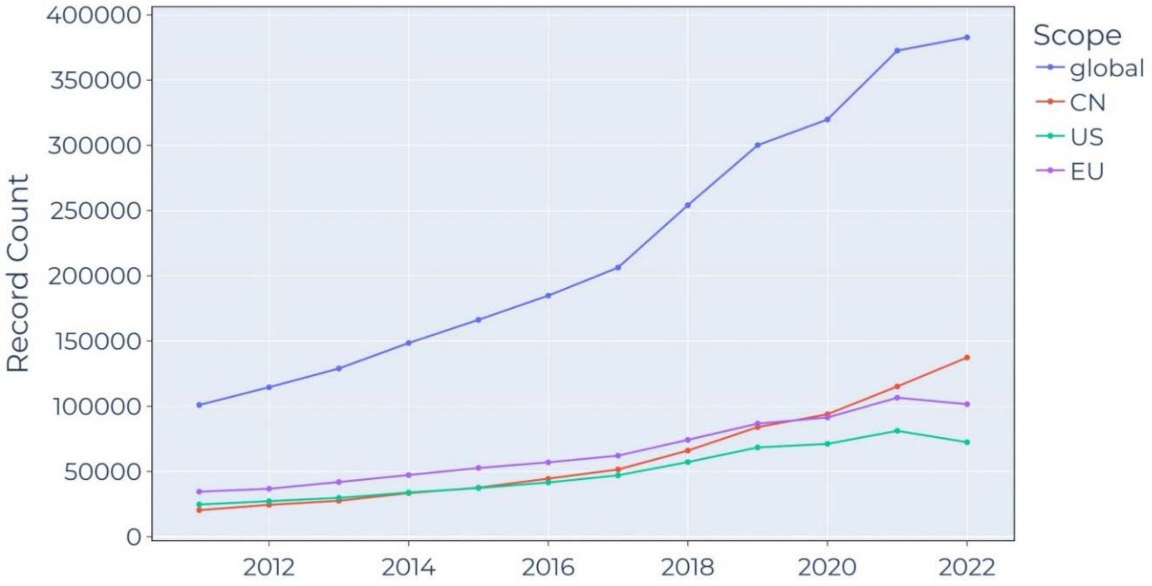


Figure 1. Number of publications per year related to artificial intelligence, machine learning and big data published by region (for keywords see Annex)

China's rapid growth in AI research has led to an intensified collaboration with the EU27/AC, especially in cutting-edge fields. While China in 2011 still had the lowest output in comparison, it

[1] European Union Member States (EU27), and associated countries (AC: United Kingdom, Norway, Switzerland) (in short: EU27/AC)

managed to overtake both the US and EU by 2022 (see Figure 1). While the number of China's AI related publications consistently continue to rise, it is important to point out that in the last year (2022) the EU-China co-publication output surpassed the CN-US output. EU-China co-publications continue to increase in numbers, in contrary to those where US researchers team up with their Chinese counterparts (see Figure 2).

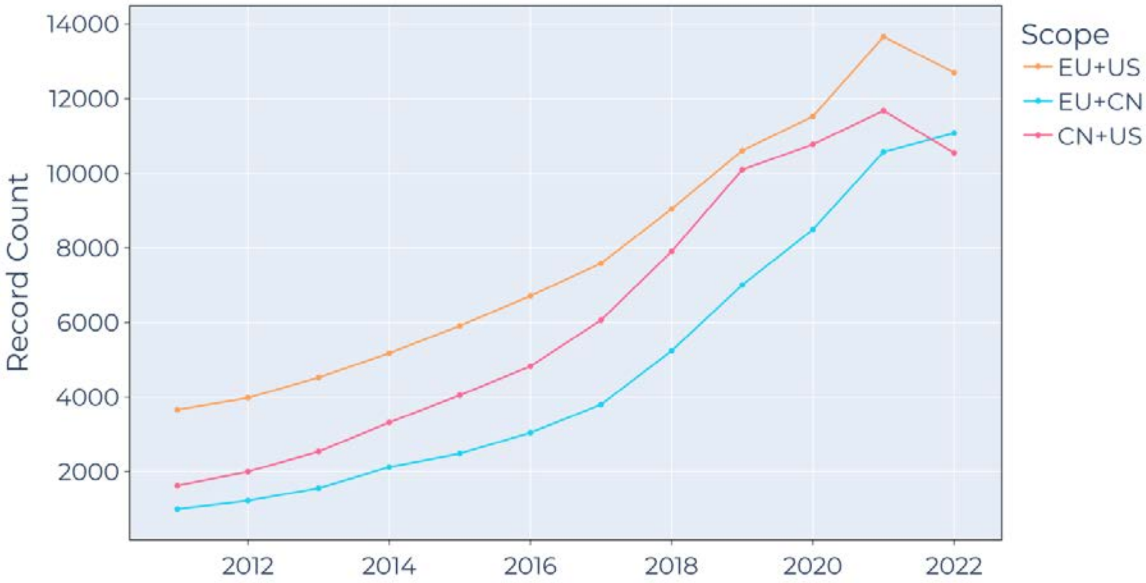


Figure 2. Number of co-publications per year related to artificial intelligence, machine learning and big data published between regions (for keywords see Annex)

Focusing on the scientific areas in the co-publications between the EU27/AC, Applied Sciences stands out as the predominant field, accounting for approximately 30k co-publications, or 65% of all collaborations between the two regions. The prominence of the AI domain, given its direct applicability, underscores this trend, indicating a close tie between research collaborations and practical applications. Natural Sciences make up another 18% of co-publications, followed by Health Sciences at 12%, Economic & Social Sciences at 3%, and roughly 2% are categorised as "Multidisciplinary." Co-publications in Arts & Humanities represent less than 1%, and due to its minimal representation, this area is excluded from further analysis. A further breakdown of the scientific areas as Domains, Fields, and Subfields according to the Science Metrix Ontology is displayed on Figure 3.

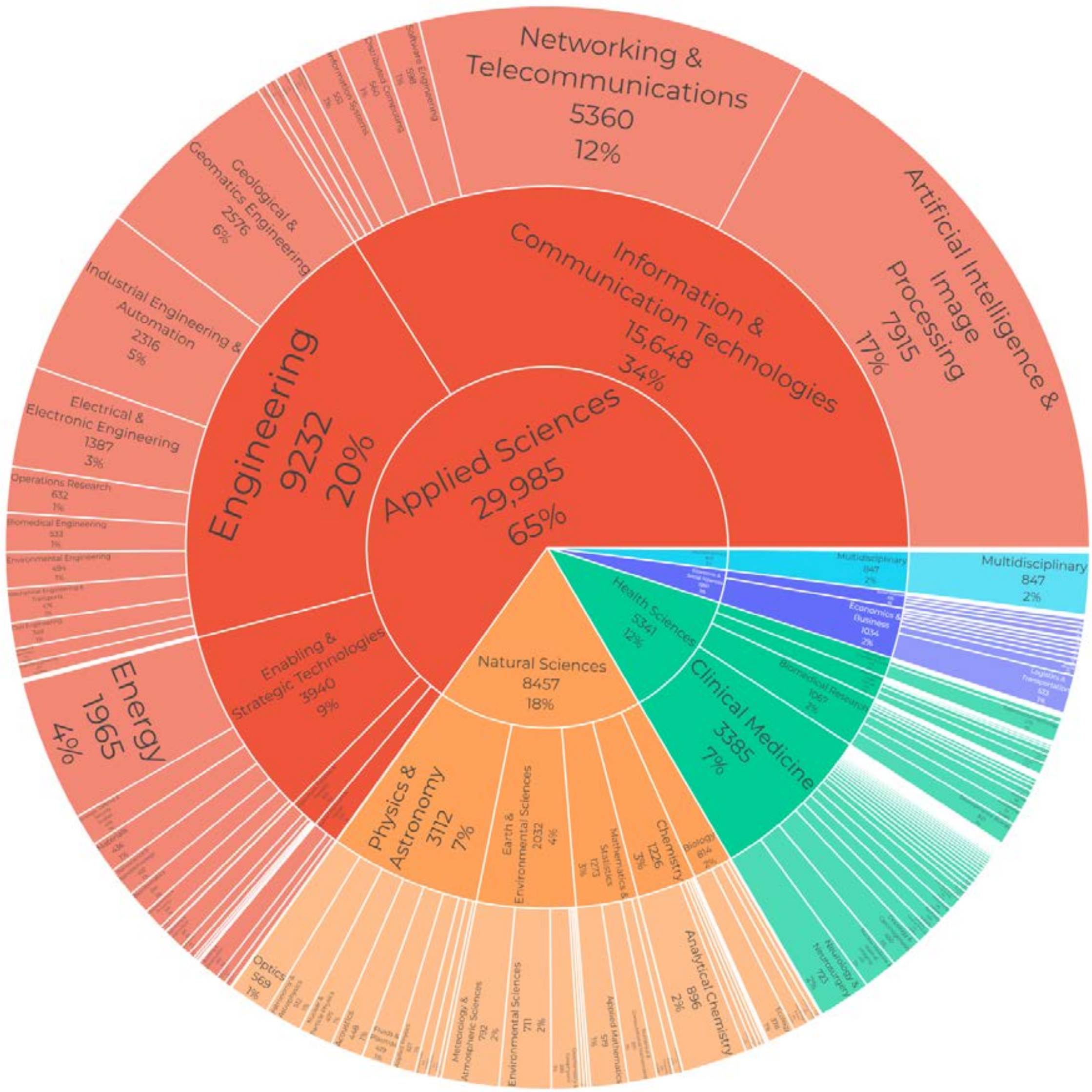
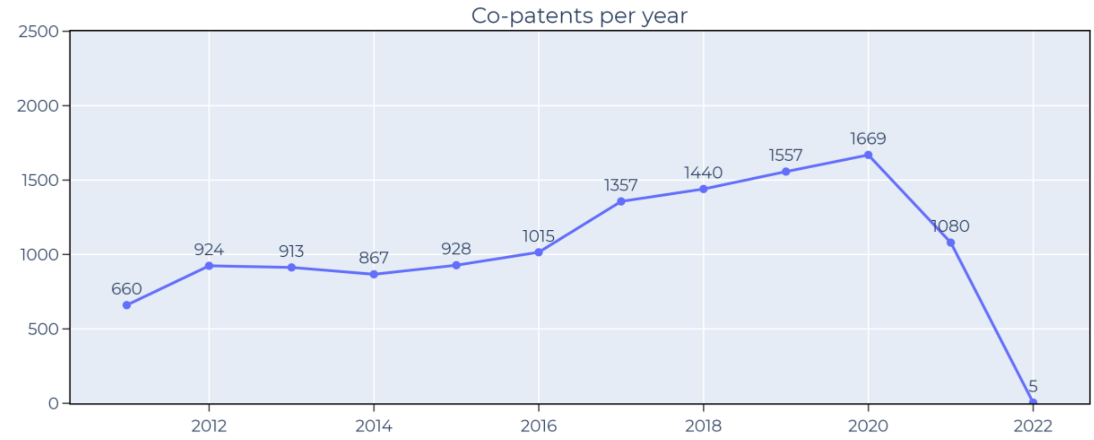


Figure 3. Distribution of scientific domains, fields, and subfields (from the inside out) of EU27/AC-China co-publications in the sectors of artificial intelligence, machine learning and big data. Classification based on the Science Metrix journal ontology.

For the analysis of co-patenting activities we made use of the IPC (International Patent Classification) system (World Intellectual Property Organization (WIPO) 2023). Our analysis reveals a symbiotic relationship in innovation between China and the EU27/AC. Figure 4 shows the yearly trends in the number of co-patent applications. Taking the time lag between patent filing and patent publication into account (more details later in this report), it shows a steady increase in co-patent applications between legal entities from the EU27/AC and China until 2020. After that, pending data on patent filing applications leads to a sharp decline of activity. Compared to the 2011 baseline, the increase in co-patent applications is steady, the number of submissions was ~1.5 times higher in 2022, thus one might expect further growth in later years (the noticeable declines post-2020 can be attributed to the inherent patent filing delays present in the PATSTAT database. It's essential to factor in this delay when interpreting recent data trends).



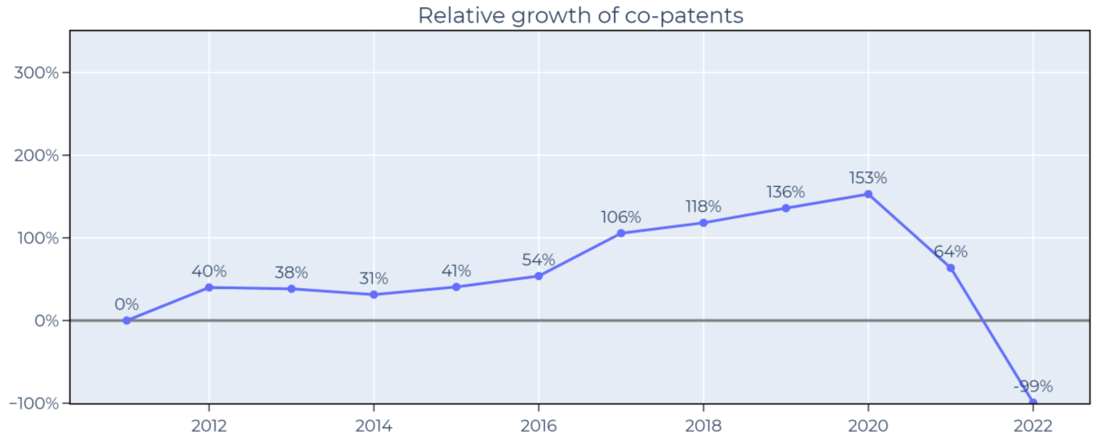


Figure 4. Overall trends in China-EU27/AC co-patent submissions; submitted co-patents per year and the relative growth in the annual submissions (indexed to 2011)

In examining the sector distribution of co-patents between China and EU27/AC, it's evident that the Electricity sector leads with 6738 joint patents (see Figure 5). Following this, Physics has 2594 co-patents, while Operations & Transporting holds 1482. The Electricity sector's co-patent filings have consistently grown over time, roughly doubling, a trend similarly observed in the Human Necessities sector. Meanwhile, there's been a marked increase in co-patent filings in the Physics, Operations & Transporting, Chemistry & Metallurgy, and Engineering sectors. Each of these sectors experienced a 2 to 3-fold rise in co-patent submissions since 2020.

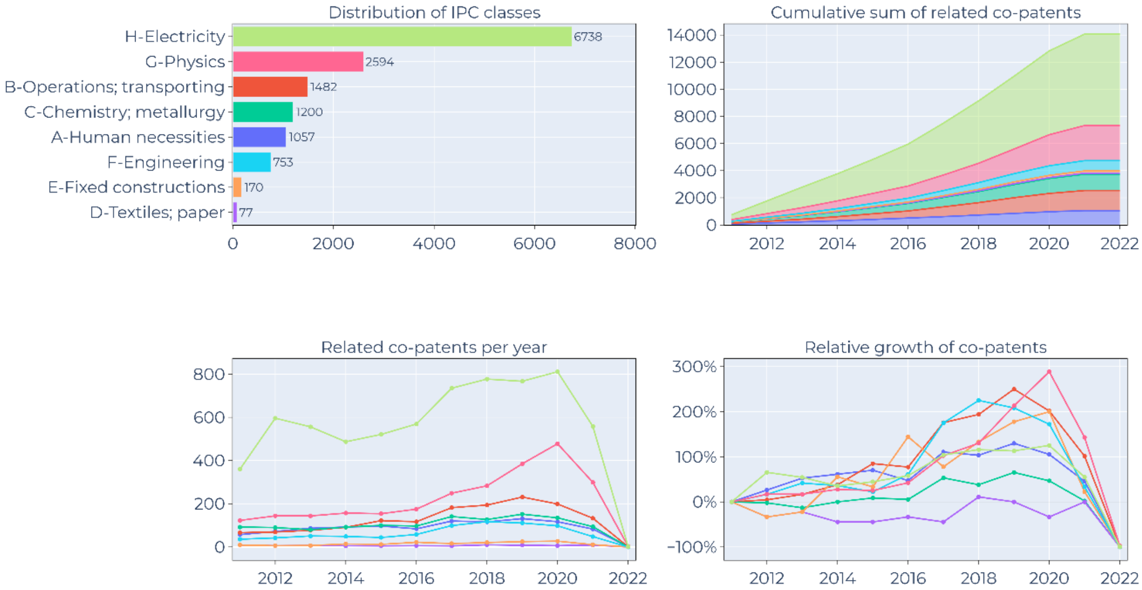


Figure 5. Detailed distribution of classes and respective tendencies of patent co-applications based on IPC patent classification

The results underscore China's significant strides in AI and big data research and its strong collaborations with European institutions in both co-publications and co-patent submissions. The dominance of Applied Sciences in co-publication data accentuates the value of insights derived from analysing co-patent submissions between China and the EU27/AC. While there are concerns about China's influence on AI-oriented research and certain scientific practices that warrant deeper scrutiny, the diverse collaboration network presented in this report offers a comprehensive overview of the varying dynamics of collaboration across different scientific areas and sectors at multiple levels of granularity.

2 INTRODUCTION

The thematic scope of the present report is embedded in the larger research objectives of ReConnect China's WP1 on science and technology. In WP1, ReConnect China aims to approach the question of science and technology in China from four separate, but related perspectives:

- China and its scientific, technological and innovation cooperation with the EU-27/AC: Most important scientific disciplines, most important economic sectors and most involved institutions (T1.1)
- Legal and regulatory aspects influencing S&T development in China, and how these impacts on EU-China STI cooperation (T1.2)
- The ambitions fuelling China's rapid acceleration in S&T development: Focus on frontier technologies (T1.3)
- The economic dimension of EU-China S&T cooperation: How China adds S&T to its outbound economy strategies, e.g. Belt and Road Initiative (BRI) (T1.4)

This report is part of T1.1 as described above. It brings together the results of our desk research and of the big data (bibliometric) analysis conducted over the past 6 months. Whereas our desk research focused on the current debate about the EU's research cooperation with China, including the position of its Member States, the big data analysis centred around thousands and thousands of entries (along with the meta data they provide) in the two databases "Web of Science[1]" (for entries on scientific publications) and "PATSTAT[2]" (for entries on registered patents) respectively. The ultimate goal of the big data-driven analysis was to search, filter and elucidate on EU27AC cooperation patterns with China in STI in most recent years with full data sets available (for both analysis done, this is the period from 2011-2022), utilising the analytical evidence gathered on jointly written publications (with at least one author from an institution in EU27/AC and one from China) and jointly applied patents (with at least one legal entity, typically a company, from EU27/AC and one from China) from the two databases.

Each of the four tasks mentioned will develop a specific research report, and together they form the cumulative research outcome of WP1. Given the four specific dimensions of science and technology the content of these reports is aligned to, we expect a certain level of complementarity between the research findings and the conclusions in each report, all of which contribute to grasp major developments in China's S&T sector better. The due date for the reports from T1.2, T.1.3 and T1.4 are M41 (D.1.2), M24 (D1.3) and M22 (D1.4).

In particular, the co-publication analysis focuses on the scientific fields of artificial intelligence, machine learning, and big data. This is mainly motivated by the rapid growth of AI research in China, which has attracted considerable attention in recent years. Coupled with the significant role that both China and the EU27/AC play in the global scientific and technological arena, this makes it an interesting and valuable area of investigation. The joint publication activity between China and EU27/AC countries already indicates a strong and growing partnership in these cutting-edge fields (see more in the forthcoming chapters).

Through contextualising our empirical findings from the big data analysis in the EU's recent attempts to recalibrate its position towards China, in particular also when it comes to foreign interference and scientific malpractices in the research and innovation sector[3], we hope this report can play its part to raise awareness about the topic and to strengthen the quality of

[1] https://access.clarivate.com/login?app=WoS&alternative=true&shibShireURL=https:%2F%2Fwww.webofknowledge.com%2F%3Fauth%3DShibboleth&shibReturnURL=https:%2F%2Fwww.webofknowledge.com%2F&roaming=true

[2] https://www.epo.org/searching-for-patents/business/patstat.html

[3] https://data.consilium.europa.eu/doc/document/ST-5396-2022-INIT/en/pdf

related expert debates. Ultimately, the report may indicate a starting point for improving EU R&I policy making on China by adding robust empirical evidence now and charting the methodological path for monitoring of EU-China STI cooperation as well in the future.

Our co-publication analysis starts by employing a large set of keywords (see Annex Table 1 for a list of the final keyword syntaxes) encompassing various fields of technology and science related thematic clusters like machine learning, deep learning, artificial intelligence, data mining, cloud computing, robotics, and more. These keywords act as our investigative lens, enabling us to thoroughly examine the expansive corpus of co-publications. They have been meticulously collected, tested, and refined through several cycles of an evaluation process. The final selection of keyword syntaxes (210) sets the frame for our dataset leveraged on the citation database Web of Science (Web of Science 2023).

Our methodology also relies on the Science Metrix (Archambault, Beauchesne and Caruso 2011) ontology for the comprehensive and granular classification of the scientific areas. As for overarching categories, the ontology contains five domains, namely Natural Sciences, Applied Sciences, Health Sciences, Economic and Social Sciences, and Multidisciplinary Sciences. The Science Metrix Ontology also introduces two additional levels of granularity - Fields and Subfields. This results in a comprehensive classification system comprising 174 unique categories, providing a detailed view of the scientific landscape. Using both the Web of Science and the Science Metrix ontology, we found exactly 46060 records that had sufficient data quality to be identified as EU-China AI-related co-publications published between 2011 and 2022.

In tandem with our co-publication investigation, we delved deeply into the co-patenting activity between China and the EU27/AC. Recognising patents as a pivotal marker of technological advancement and innovation, this study taps into the expansive PATSTAT database (Data Catalog PATSTAT Global 2023 Spring Edition 2023) to unravel the intricacies of collaborative patenting endeavours between these regions. Spanning the period from 2011 to 2022, our primary focus was on the initial filings of Patent Cooperation Treaty (PCT) (World Intellectual Property Organization (WIPO) 2023) patent applications, offering a fresh and comprehensive perspective on the most recent and relevant patenting activities.

To provide structure and meaningful insight to our patent data, we employed a categorisation system. This system, designed to categorise patents based on the technologies they encompass, aids us in grouping relevant technologies and pinpointing the industrial sectors that are most prominently in the limelight of collaborative innovation. From application authorities and inventorship to the determinants of industrial sectors, our analysis is comprehensive, ensuring that we cover the multifaceted dimensions of co-patenting activities.

The detailed examination of patent data offers a nuanced understanding of the technological collaborations between China and the EU27/AC countries. Such collaborations, often underpinned by shared interests, expertise, and the pursuit of technological frontiers, highlight the symbiotic relationships forming in the realm of innovation. Leveraging the PATSTAT database and the IPC system has equipped us with the necessary tools to extract, interpret, and present these insights, enriching the overarching narrative of our research.

In conclusion, this study contributes to the understanding of international scientific collaboration, offering insights that could guide policy decisions, foster international cooperation, and drive future research directions. The findings reveal that China has significantly advanced its AI, and Big Data related research, and is actively engaging in partnerships with European institutions, however, concerns about potential influences on AI-oriented research and certain scientific practices in China require further investigation. The results also yield a diverse collaboration network between the Chinese and EU27/AC institutions with different dynamics under different scientific domains, fields, and subfields. Moreover, the study not only provides a snapshot of the current state of Chinese-EU27/AC scientific collaboration, but also offers a chronological perspective, tracing the evolution of these collaborations over time. This temporal focus allowed us to highlight specific trends and shifts, providing a richer understanding of the collaborative landscape.

3 METHODOLOGY

3.1 Co-publication analysis

The co-publication analysis between China and the EU27/AC for the period 2011-2022 is based on Clarivates's Web of Science (short: WoS), one of the best known and most comprehensive multidisciplinary academic citation databases. Web of Science is built on the following databases (the so called “Core Collection”):

- Science Citation Index Expanded (SCI-EXPANDED)
- Social Sciences Citation Index (SSCI)
- Arts & Humanities Citation Index (A&HCI)
- Conference Proceedings Citation Index- Science (CPCI-S)
- Conference Proceedings Citation Index- Social Sciences & Humanities (CPCI-SSH)
- Emerging Sources Citation Index (ESCI)
- Book Citation Index - Science (BKCI-S)
- Book Citation Index - Social Sciences & Humanities (BKCI-SSH)
- Index Chemicus (IC)
- Current Chemical Reactions (CCR-EXPANDED)

In order to align the research question of T1.1. more with the activities carried out in the other tasks of WP1, a specific focus was chosen for the co-publication analysis. Based on joint discussions between WP1 participants, the scientific topic of “Frontier Technologies” appeared most suitable to build a bridge between the single research questions pursued in each task: T1.1 aims to assess the dimension of research cooperation in specific niches of frontier technologies between EU27/AC and China. T1.2. explores more in detail the legal and regulatory ramifications of China's state-led support for advancing own frontier technology developments and how this impacts on the cooperation with the EU. T1.3 has a slightly broader focus by researching on China's most recent attempts to leapfrog in the development of space technology as another frontier technology as well. T1.4 finally sheds more light on the economic effects of EU-China S&T cooperation, not only but also what concerns frontier technologies.

As a consequence, the following scientific fields were used to define the search scope for the co-publication analysis:

- Artificial Intelligence (AI)
- Machine Learning
- Big Data

In a next step, we gathered a sufficient amount of relevant keywords related to these fields, based both on previous bibliometric studies and on the knowledge of experts available. To ensure the relevance and precision of these keywords, we subjected them to rigorous quality checks and adjusted their syntax. Having arrived at a final set of keywords (210 different keywords in total), we utilised them as an input on the WoS user interface relying on 'topic search'. The topic search method of the WoS query procedure looks for correspondences within the title, the abstract and the keywords of database entries. As a time horizon for our analysis, the last ten fully available years were chosen (2011-2022). For the complete query including a filter for relevant countries and timeframe, please see the annex to this report.

Drawing on this query design, the results found cover all scientific publications indexed in the WoS Core Collection featuring an affiliation to at least one organisation in China and one in the EU27/AC countries and that were published between 2011-2022. The study does not discriminate by document types, meaning that scientific articles are equally counted like any other type of scientific output, such as conference proceedings, academic letters, abstracts etc. (or any other document types that were tracked by the WoS Core Collection). We consider such types of scientific outputs as equally reliable indicators for joint cooperation activities, which makes them import subjects for our analysis as well.

To understand and adequately interpret the results presented in this deliverable, a few key terms frequently used in the remainder of this report need to be defined at this point. With the term **'record'**, we refer to an entry in our database containing the meta-data of a uniquely identified publication. Throughout the study, we use **full counting** of records instead of **fractional counting**. This means that a record that is jointly published in a journal by authors from, e.g., Germany and China, is counted as one publication for Germany and one publication for China. The decision for full counting over fractional counting in our context relates to the interest in international scientific collaboration over the recognition of authors – or in other words: For the scope of this specific analysis, we are not interested in the authors behind a publication, but in the institutions, they work with and the host countries. From this point of view, it does not matter whether a Chinese author publishes with four colleagues from Germany (which, in fractional counting, would mean 0.8 publications for Germany) or with one. The important fact relevant for us is that there is a contribution from Germany. However, in a pair-wise view of the collaboration between Germany and China in the above example (see collaboration matrices between institutes), the co-publication counts as one jointly produced article, and not as two. An **'affiliation'** links an author to her/his institution(s). As these can be more than one and they can be also located in different countries, all of these affiliations are counted in co-publications.

For the analysis of output and collaboration per **subject area**, we use the ontology developed by Science Metrix, which assigns each journal (and, by extension, records published in the respective journal) to one **thematic field**. The ontology distinguishes between three levels of granularity: **research domains** (6 in total), **research fields** (21) and **subfields** (175). If a specific journal was not indexed by Science Metrix, we use and **ad-hoc classification** method. In this step we rely on using the WoS-own classification ontology of the record to find the most similar journal indexed according to the Science Metrix ontology and apply the respective classification that we found on the un-indexed record. In some cases, we apply the **EuroVoc classification**[1] to EU27/AC countries to establish regional differences.

Data processing: The raw data in the WoS Core Collection, as we retrieved it, are, to some extent, of limited quality. Errors range from wrong address information to inconsistent affiliation names. In order to mitigate these flaws, a bundle of data-processing protocols was developed specifically aimed at harmonising this meta data information on the entries found.

3.1.1 A note on the impact factor

When it comes to the bibliometric analysis of publications, the notion of **'impact'** (i.e., number of citations, usually referred to as a quality metric of a publication) is often discussed and debated. In fact, the way of measuring the importance or relevance of a publication can be hardly standardised due to several factors. First of all, the actual number of citations is always just a snapshot. Since there is a considerable time lag between the publication of a scientific work and the occurrence of references to this work in the publications of other authors, the most recently published works will typically show no or few citations. The citations of a very recent publication cannot be compared to the ones of a publication which was published some years ago. Unfortunately, WoS does not provide high-quality data regarding publication date. Secondly, if

[1] „7206 Europe: Concept Scheme," Publications Office of the EU, 2023. [Online]. Available: https://op.europa.eu/en/web/eu-vocabularies/concept-scheme/-/resource?uri=http://eurovoc.europa.eu/100277

looking at the citation count of a publication, the scientific field in which it was published may attain a decisive role. Natural, Health or Applied Sciences are usually highly cited research fields, whereas others such as Social Sciences or Arts & Humanities tend to have lower citations rates. Last, but not least several additional factors can play into the number of citations, such as the status and the number of authors, the profile of the institutions etc. All these particularities together considerably affect the development of a uniform impact measure methodology. And out of this consideration, the analysis of impact is, on purpose, not part of this report.

3.2 Co-patent analysis

The co-patent analysis offers an industry-focused perspective on innovation and technological collaboration between China and EU27/AC countries. Our investigation in this report centres on patent applications that meet the following criteria: They were filed at Chinese or EU patent offices and they were developed collaboratively between at least one inventor in China and one in the EU or they are owned by at least one legal entity from either region. As already mentioned in our introduction, we've sourced our data from the PATSTAT database of the European Patent Office, more specifically from the dataset called “PATSTAT Global 2023 – single edition (spring edition)[1]”. Within this dataset, we filtered for initial filings of PCT patent applications submitted between 2011 and 2022.

It is important to understand that the process from patent application to patent granting is not straightforward. Whether or not a patent application results in a granted patent depends on various factors, such as – not surprisingly – the content of the application, but also the strategy that is pursued by the applicants themselves. On the strategy, the objective may be to simply protect an invention through a patent application in order to prevent others from patenting the same idea – without any deliberations on the potential for commercialisation. Against this background, a patent application is still considered a strong indicator for new, codified knowledge that the applicants deem important enough to disclose. In view of our research question for this co-patent analysis, it is this data on patent applications we are focusing on and working with. Patent applications will help us to answer the following main question and related sub-questions:

- Which companies from EU27/AC and China were mostly involved in joint patent applications and in which technological fields were most patent applications made?
- How did the number of applications evolve over time (2011-2022)?

[1] https://shop.epo.org/en/Data-and-services/Bulk-data-sets/PATSTAT-%28bulk-data-sets%29/PATSTAT-Global/p/PSBKF-A

- Are there any implications from the co-patenting activities found to the EU's current approach on de-risking[1] from China?[2]

Applications with multiple inventors and owners from different countries, or those filed under more than one technology class, can be assigned to each country or class either entirely or partially, depending on the total number of entities. These patents can be attributed either partially (**fractional counts**) or entirely (**full counts**) to each country listed (comparable to fractional and full counting in the bibliometric analysis). The methodology we've adopted for this analysis is the full-count method, consistent with our co-publication analysis.

Patent applications can be of different format, varying in procedure, cost, scope, and protection subject (e.g., registered design). This study primarily considers the following two types: **national (type 'A') and international (type 'W') applications**.

Type A/National applications are filed in a national or regional patent office and seek protection in a single market. The patent office then reviews the application to determine if the invention is novel, non-obvious, and industrially applicable. The application is usually published around 18 months after filing, irrespective of the review outcome. In the case of a positive review (confirming patentability), the applicant decides whether to proceed with obtaining a granted patent and whether to pay the necessary fees this step implies. As patents are territorial rights, national patent applications must be filed separately in each national office, which means multiple applications can refer to the same invention.

A cost-saving procedure, established by the Paris Convention for the Protection of Industrial Property in 1883[3], allows applicants to first file a national application in their home patent offices, followed by a 12-months window to file subsequent applications in other office abroad. This includes the possibility of filing a PCT patent (Patent Cooperation Treaty[4]) based on the initial filing. These subsequent applications share the same priority date as the first application, meaning that the effective protection starts from the same day. In In the context of this study, it's imperative to emphasize initial filings. These signify the first official documentation of an invention or innovative idea. Given that a patent can be filed multiple times in different jurisdictions or under

[1] The idea for de-risking was promulgated by EC President Ursula von der Leyen in a speech on March 30, 2023. https://ec.europa.eu/commission/presscorner/detail/en/speech_23_2063

[2] N.B. This question is not covered in this report, but merits to be addressed in a follow-up activity

[3] https://www.wipo.int/treaties/en/ip/paris/

[4] https://www.wipo.int/pct/en/

different classifications, focusing on the initial filings helps us "de-duplicate" the data, ensuring we're analysing unique inventions without repetition.

Regarding type W/International applications, the application process follows the PCT procedure for international filings. An international application for a PCT patent can be filed at any IP office in any PCT signatory state, in any regional office, or directly at WIPO. The application undergoes an international phase followed by national phases in the countries chosen for protection. Eventually, the PCT application translates into a set of national patents. The international application for a PCT patent is generally cheaper, easier, and faster than filing multiple national applications.

Generally the OECD (Organisation for Economic Cooperation and Development) Patent Statistics Manual[1] advises against comparing 'A' level patent applications due to potential variations in scope and filing process between countries, yet in the case of the EU27/AC countries it is safe to assume that national IP systems in Europe are not differentiating too much, and the patent filing practices of China has caused that no co-patent were found filed at Chinese patent authorities (lack of documented national information; see Results). Other protectable features of a patent like registered designs or utility models were not considered in this analysis.

The PATSTAT dataset features coverage of both 'A' and 'W' patent applications, meaning a significant advantage for our research design. In total it contains over 80 million records from around 90 patent authorities. While not fully comprehensive in terms of global coverage, PATSTAT aims to offer the best possible approximation by covering all major patent authorities worldwide. Of particular benefit for our analysis are the harmonisation of inventor and applicant names and its standardised letter system, both by default. In view of our need to transliterate patent meta data from Chinese into English in for patent applications in Chinese, this PATSTAT-own feature is of particular practicability to us.

In addition to the type A and W criteria, there are a few more specificities that need to be taken into account when dealing with PATSTAT global patent applications: **First, there are two types of actors involved in the full process of a patent application**. The inventor(s) on the one, and the applicant(s) on the other hand. While the inventor is the individual who developed the piece of knowledge, the applicant (most often a company) is the one who registers and therefore formally owns the patent application. The knowledge (in form of a process, technology, product etc.) is registered at a **specific patent authority**, and this is the second specificity in the patent

[1] https://www.oecd.org/sti/inno/oecdpatentstatisticsmanual.htm

application data. In particular for the question where a patent application was done, one should exactly know which type of “where?” is supposed to be answered: The location of the inventor of the knowledge, the location of the owner of the knowledge and the location where the knowledge was first registered (filing of the patent), they all make a critical difference.

Our analysis of patent applications is structured across multiple dimensions of entities:

- **Patent Authorities**: We examine the patent applications at the level of national patent authorities. This provides insights into how different jurisdictions assess and process patent applications.
- **Inventors’ Country of Origin**: We investigate the patent activity based on the country from which the inventors hail. This dimension offers a geographical perspective on innovation hotspots and trends.
- **Applicant Level**: Our analysis also delves into the entities — be they individuals, organizations, or companies — that have filed the patents. This sheds light on which stakeholders are driving innovation.

For each of these dimensions, we incorporate specific analyses of international cooperation patterns. These are integrated into their respective chapters, ensuring a thorough understanding of collaboration dynamics, be it at the inventor or applicant level.

Finally, patents can be categorised according to the technology the invention represents. The most common classification system is the IPC system that is rooted in the WIPO’s Strasbourg Agreement (1975)[1]. The IPC system provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. The IPC divides technology into eight sections with approximately 70,000 subdivisions. Each section is divided into classes, subclasses, groups and so on. The eight IPC sections are:

• A (human necessities)

• B (performing operations; transporting)

• C (chemistry; metallurgy)

• D (textiles; paper)

[1] https://www.wipo.int/treaties/en/classification/strasbourg/

- E (fixed constructions)
- F (mechanical engineering; lighting; heating; weapons; blasting)
- G (physics)
- H (electricity)

Note, however, that patents can be associated with multiple IPC symbols, indicating that they cover innovations in more than one technological area. Thus, the IPC system is not exclusive; a single patent can span multiple categories of technology, reflecting its multifaceted nature.

3.3 A note on entry delay

In both datasets (co-publications and co-patents) we had to accept and deal with the time lag between the moment when a publication on the one or a patent application on the other hand was done and the appearance of a related entry in the respective database.

The time lag for an article to be indexed in Web of Science WoS following its publication can be of different extent, but on average it ranges from a few weeks to several months. After an article is published, the indexing process begins with the identification and submission of the article to WoS. The time until this first step depends on common factors related to publishing houses, such as the quality of the information on the publication provided by the publisher to WoS. Once submitted, the article undergoes an evaluation process by the WoS indexing team. During this evaluation the quality and relevance of the article is assessed. If there is a high volume of submissions or if the article requires a more in-depth evaluation, this can imply additional time for assessment. Technical issues, corrections requested by the indexing team, or any other administrative factors may also add to delays in the indexing process.

The EPO PATSTAT database primarily sources its patent data from national patent offices. These offices usually publish patent applications within 18 months of filing, but some can take longer. Once published, the data's integration into PATSTAT depends on the reporting speed of each national authority, leading to a delay that can span between two to four years. Consequently, PATSTAT's data for the very recent years, such as 2021, 2020 and 2022, remains incomplete and should be interpreted with caution. However, for 'W'/PCT patent applications, the data is more timely since it's sourced directly from WIPO registers rather than individual national authorities.

Despite any of these constraints in the availability of data, PATSTAT and WoS are by far the best available sources for an analysis like ours.

4 RESULTS

4.1 Co-publication analysis

4.1.1 Global overview of publications in the field of AI

In the period from 2011 to 2022 (12 years), the global scientific output in terms of scholarly publications in the sectors of AI, machine learning and big data (exact definitions follows a set of keywords, see Annex; for abbreviation reasons we use “AI” in the further text, but AI, machine learning and big data are meant) indexed in the Web of Science amounted to ca. 2.6 million publications. Out of those, 793k (thousand) were published by researchers in the EU27/AC, 736k by Chinese and 592k by US researchers. Regarding publication dynamics, China had the highest growth rate of AI publications in the analysed period. While China in 2011 still had the lowest output, it managed to overtake both the US and EU by 2022. Moreover, contrary to the stagnating output rate of the others, China continues to show a growth rate. (Figure 6)

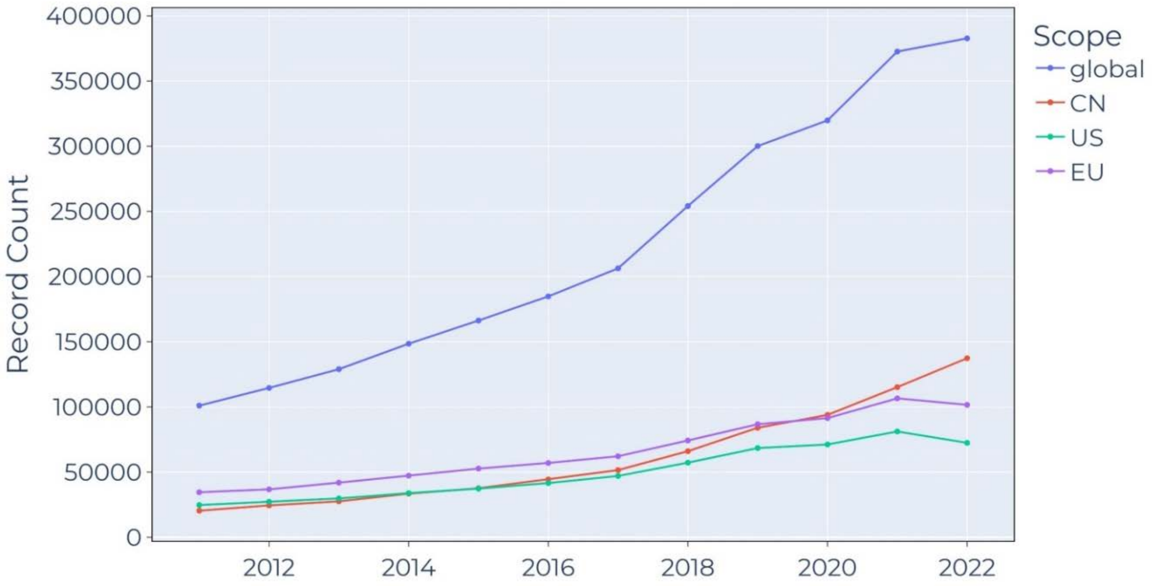


Figure 6. Number of publications per year related to artificial intelligence, machine learning and big data published by region (for keywords see Annex)

In terms of jointly written publications between at least one author from two different regions (USA, EU27/AC, China: for reasons of abbreviation, we use “EU” in the further text, but EU27/AC are meant) the data includes 95k EU-US, 75k US-China and 57k EU-China co-publications. However, it is important to point out that in the last year (2022) the EU-China co-publication output surpassed the CN-US output. EU-China co-publications continue to increase in numbers, in contrary to those where US researchers team up with their Chinese counterparts. (Figure 7)

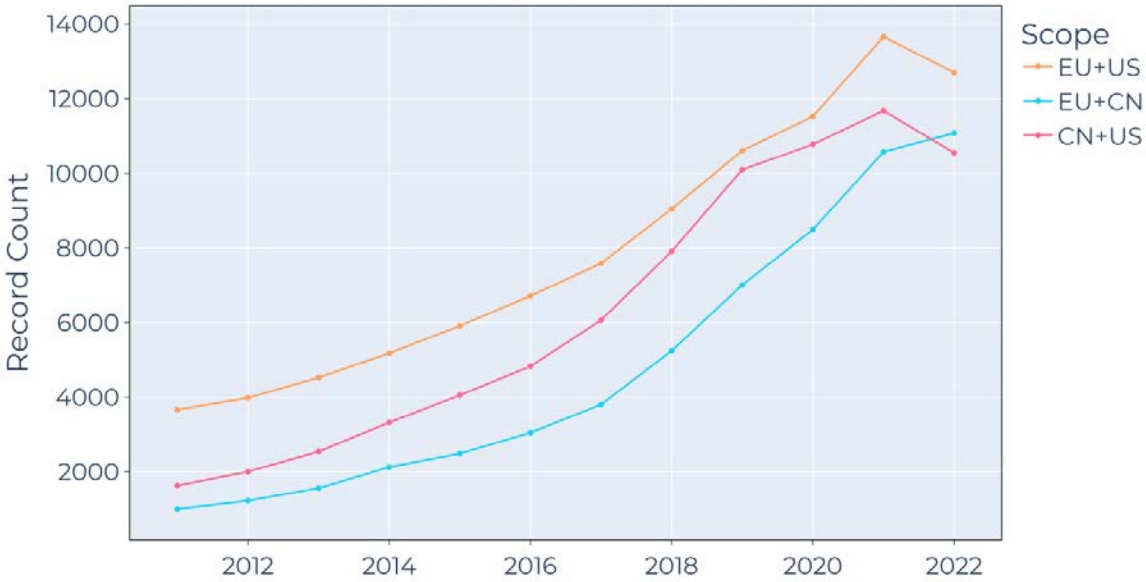


Figure 7. Number of co-publications per year related to artificial intelligence, machine learning and big data published between regions (for keywords see Annex)

Scrutinising the 57k EU-China co-publications more in detail, we found exactly 46060 records with sufficient data quality to corresponded them to the Science Metrix classification system (other records were either not indexed by the Science Metrix, or turned out to be single author records with European and Chinese affiliation at the same time). In the remainder of this chapter, this volume of records defines the scope of our bibliometric analysis.

4.1.2 Overall patterns in EU27/AC-China co-publication activities

Figure 8 illustrates the development between EU-China co-publications over time. The yearly co-publication output increased from 822 in 2011 to more than 9.5k in 2022, which is a more than tenfold increase.

Figure 8. Number of co-publications per year and relative growth of yearly output (indexed to 2011) related to artificial intelligence, machine learning and big data published between China and EU27/AC countries.

Figure 9 illustrates the overall distribution of all research areas (decreasing hierarchy from the inside out: domain, field, and subfield) in which co-publications between the EU27/AC and China were done. In this broader scope of analysis, the dominating field are Applied Sciences with ~30k co-publications in total, equal to 65% of all co-publications between the two regions. Such a high focus on applied approaches highlights the importance of our co-patent analysis. The reason being co-patenting endeavours between the EU and China are predominantly concentrated in the telecommunications, IT, and electronics sectors. Additionally, the AI domain, with its immediate applicability, further reinforces this trend, suggesting a strong alignment between research collaborations and practical implementations.

Another 18% of the co-publications belong to the Natural Sciences, 12% are in Health Sciences 3% in Economic & Social Sciences and roughly 2% are not specific to any scientific field, thus they are registered as “Multidisciplinary”. Less than 1% of co-publications relate to Arts & Humanities, and for this reason we are omitting this latter research area from the further analysis.

Following the synopsis on research domains, we further tailor our focus to research fields. In the domain of Applied Sciences, the fields of Information & Communication Technologies (34%), Engineering (20%) and Enabling & Strategic Technologies (9%) are most popular. In Natural Sciences, Physics & Astronomy (7%) and Clinical Medicine (7%) are those fields with the highest total proportion.

Finally, on the level of research subfields, the most frequent topics of co-publications relate again to the Applied Sciences. These are:

- AI & Image Processing (17%)
- Networking & Telecommunications (12%)
- Geological & Geomatics Engineering (6%)
- Industrial Engineering & Automation (5%)
- Energy (4%)
- Electrical & Electronic Engineering (3%)

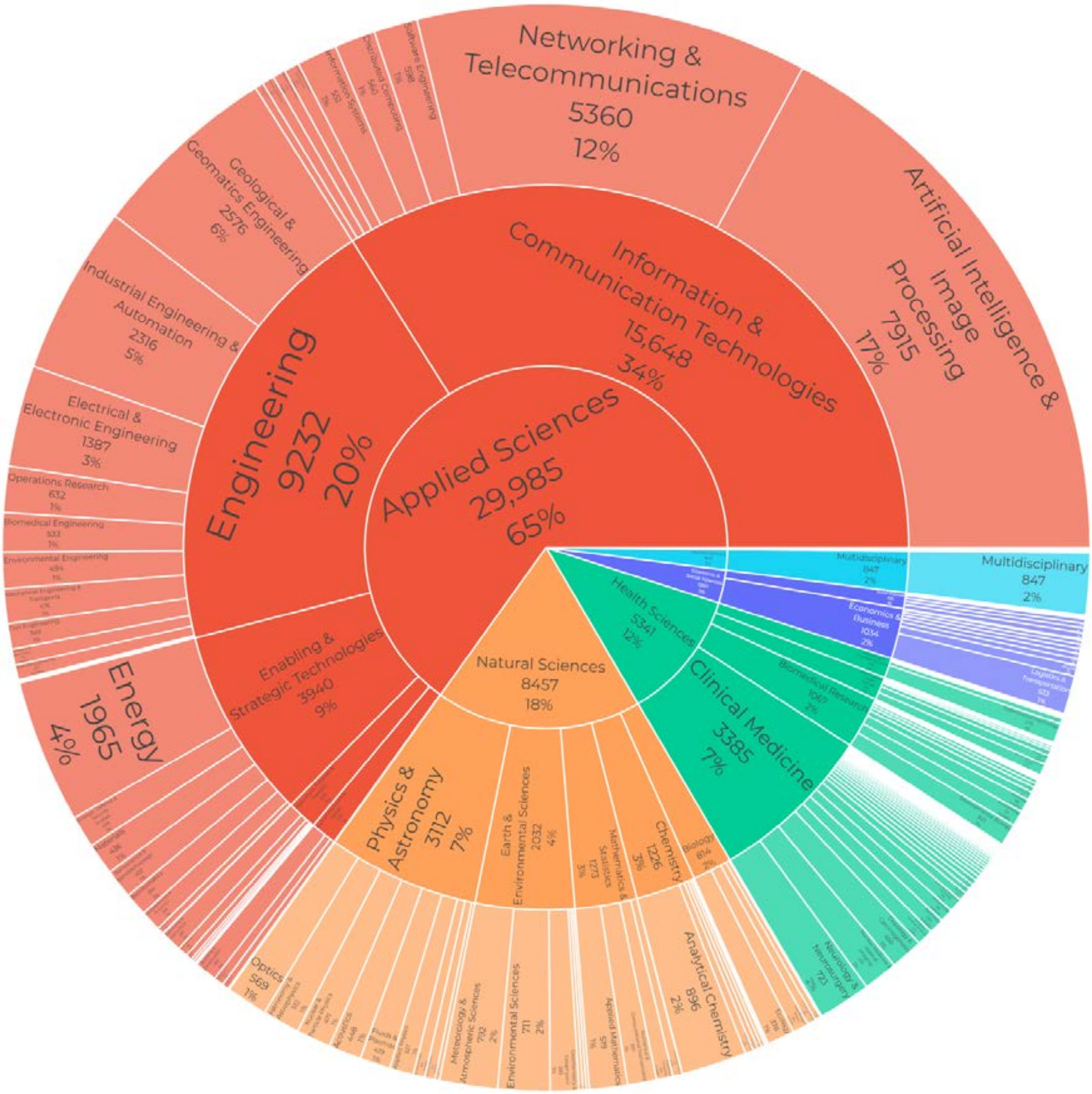


Figure 9. Distribution of scientific domains, fields, and subfields (from the inside out) of EU27/AC-China co-publications in the sectors of artificial intelligence, machine learning and big data. Classification based on the Science Metrix journal ontology.

The yearly development of co-publications across all scientific domains, in which AI-related co-publications have been published, is shown in Figure 10. One can clearly grasp the numerical dominance of co-publications categorised in Applied Sciences over the full period of our analysis. On the other hand, it is important to note that in terms of relative growth multidisciplinary co-publications were the most prolific in the early years (2011-2017), whereas publications within the Economic & Social Sciences have recently become trending.

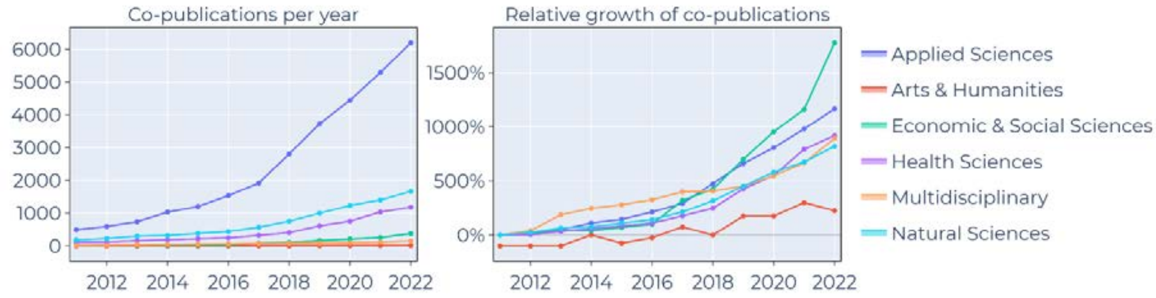


Figure 10. Yearly development of AI-related co-publications by scientific domains. Scholarly output per year and the relative growth in annual schoraly output of co-publications indexed to 2011.

4.1.3 Country-level analysis

Figure 11 shows the overall country level contributions to total co-publications of the EU27/AC countries. Figure 12 then shows the developments over time (percent of co-publications related to country). The overwhelming majority (44%) of AI-related co-publications between the EU27/AC and China had at least one author from the UK. Authors from Germany (15%) France (11%) Italy (8%) the Netherlands (7%) and Spain (6%) in co-publications with China follow then. Authors from countries of the Baltics and Central-Eastern Europe contributed to only to 6% of co-publications in total. Except from France, whose co-publications decreased from ca. 14% to 9% by the end of 2022, no other country shows any significant changes in terms of yearly development, but only slight fluctuations (Figure 12).

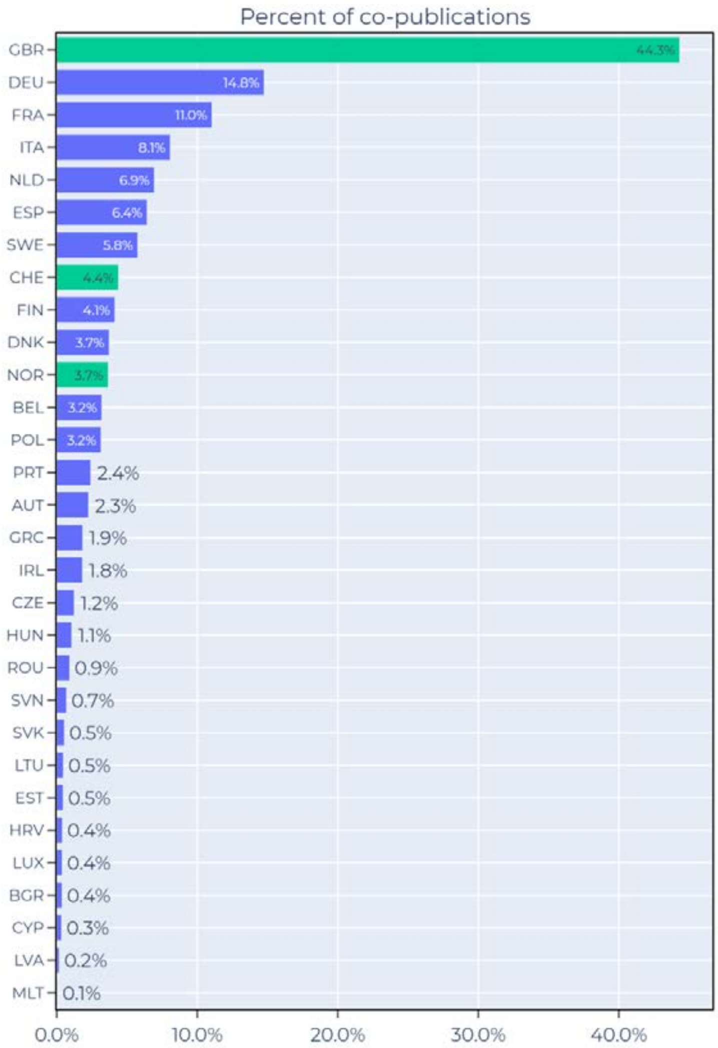


Figure 11. Overall country level contribution to co-publications of EU27/AC countries (in percent of entries related to country; see Methods section)

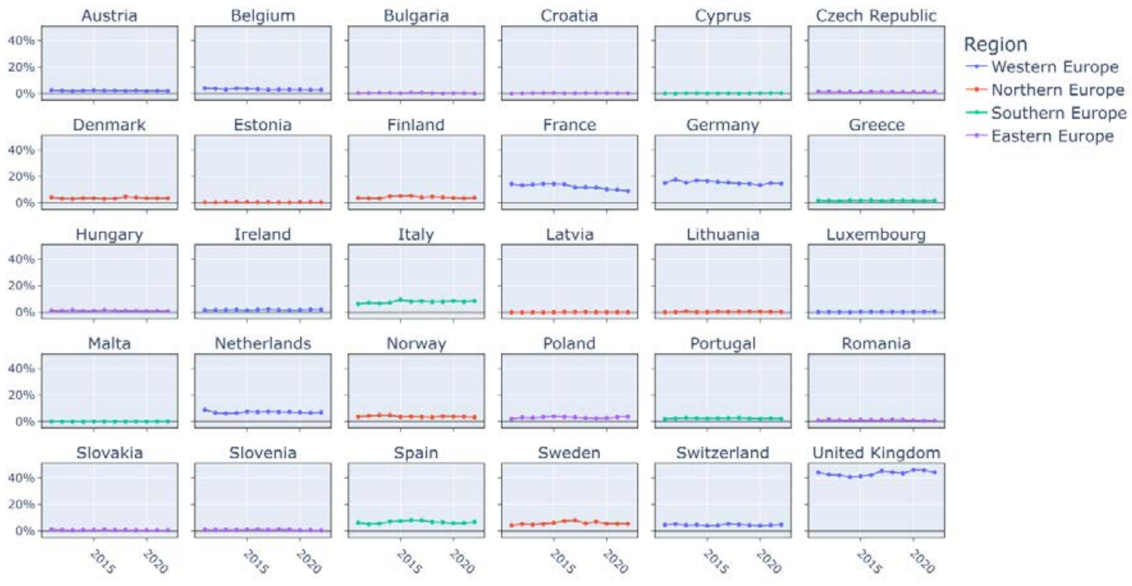


Figure 12. Yearly development in country level contribution to co-publications of EU27/AC countries (in percent of entries related to country; see Methods section).

The relative increase in co-publications per country is illustrated in Figure 13. What can be said upfront is that all countries managed to increase their co-publication output by at least a factor of seven. In this respect, some of the countries experienced an anomalously huge growth rate (Lithuania, Latvia, Croatia, Cyprus, Luxembourg), which has to do with their very low scientific output at the first year of analysis (only one or two co-publications in 2011). Poland, on the other hand, shows a significant, almost 20-fold increase in co-publications (2011: 17 records, 2022: 353 records). It is also important to emphasise the recentness of growing output numbers: In most countries this is a relatively recent and sudden trend, emerging after 2020 only. The overall regional growth rates were lowest in Eastern Europe (about 7.5-fold increase) and highest in Northern and Southern Europe. Western European co-publications' relative growth rate was about 10 times in 2022 than 2011.

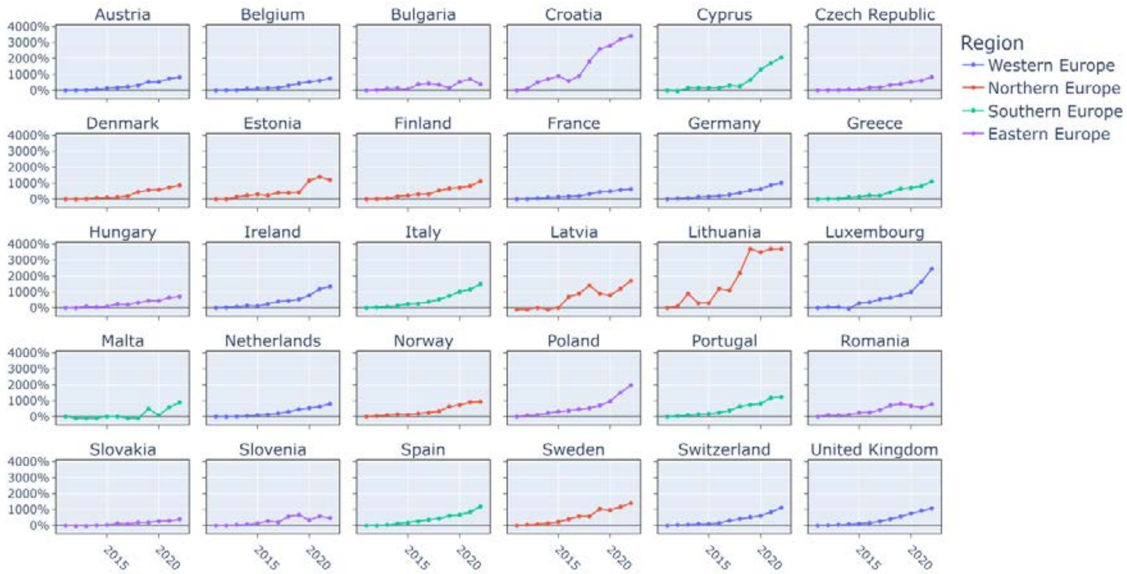


Figure 13. The relative growth in annual scholarly output of co-publications with China (indexed to 2011) by country.

4.1.4 Institution-level analysis

Our dataset contains 17031 unique institutions involved in EU27/AC co-publication activities, out of which 9807 are based in EU27/AC and 7224 are based in China. Figure 14 shows the total number of institutions involved in co-publications across the EU27/AC countries.

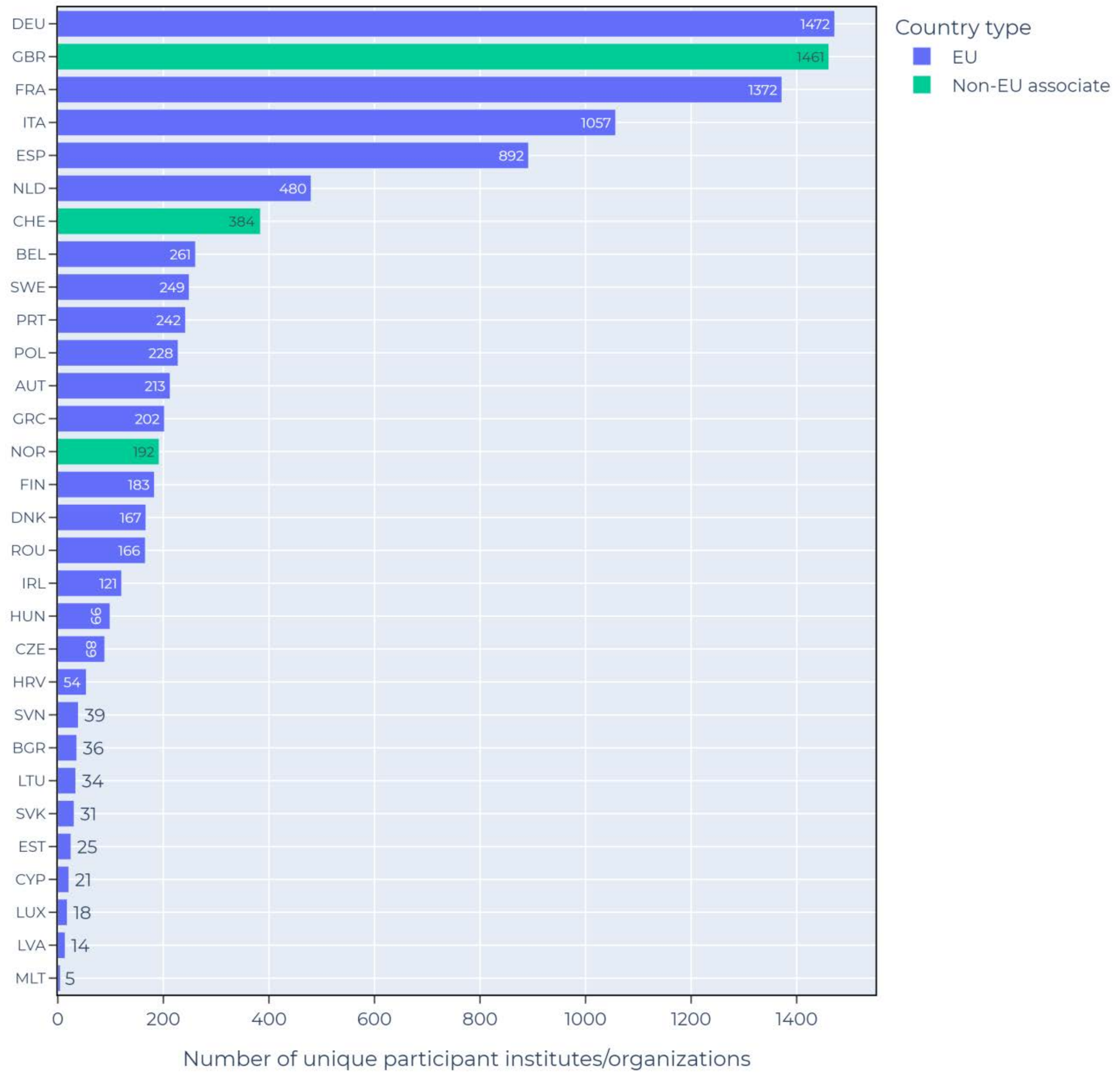


Figure 14. Number of unique institutions in EU27/AC countries participating in co-publication activities with China

On such a large number of institutions it is not feasible to depict every single institutional cooperation between the EU27/AC and China. As a result, we decided to focus on the most dominant institutions and their cooperation patterns only. Figure 15 casts more light on the top-25 institutions from EU27/AC having collaborated with China in AI-related publications. Given the overly dominant role of the United Kingdom in co-publications with China (compare the share in % in Figure 11), it is not surprising to meet same patterns at the institutional level. From the top-25 institutions only these six are non-UK:

- Delft University of Technology (The Netherlands)
- Technical University of Munich (Germany)
- Royal Institute of Technology (Sweden)
- Swiss Federal Institute of Technology (Switzerland)
- Aalborg University (Denmark)
- University of Oslo (Norway)

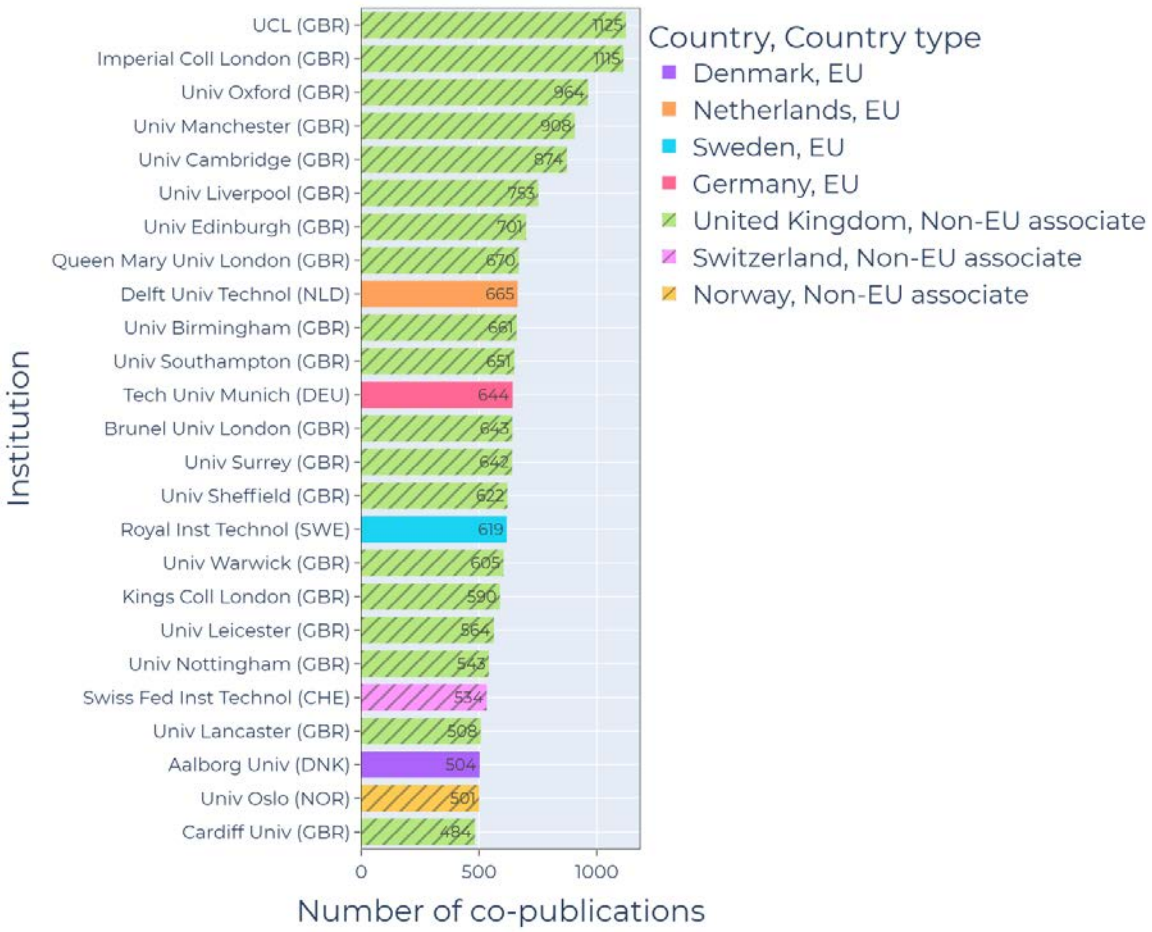


Figure 15. Top 25 most active institutions (EU27/AC countries) publishing on AI-related topics in collaboration with Chinese institutions

Another interesting approach is the same analysis without the associated countries United Kingdom, Switzerland, and Norway. In Figure 16 only the top-25 EU27 institutions are listed. Excluding the UK from the analysis leads to Western and Northern European institutions climbing up the ladder. These patterns seamlessly overlap with our country-level results, where mostly countries from these parts of Europe concentrate after the UK. With the Polish Academy of Sciences, we meet a complete outlier though. It is the 5th most productive EU27 institution and the only one from Eastern Europe in the top-25. In a later chapter we will provide another, more granular interpretation of this data.

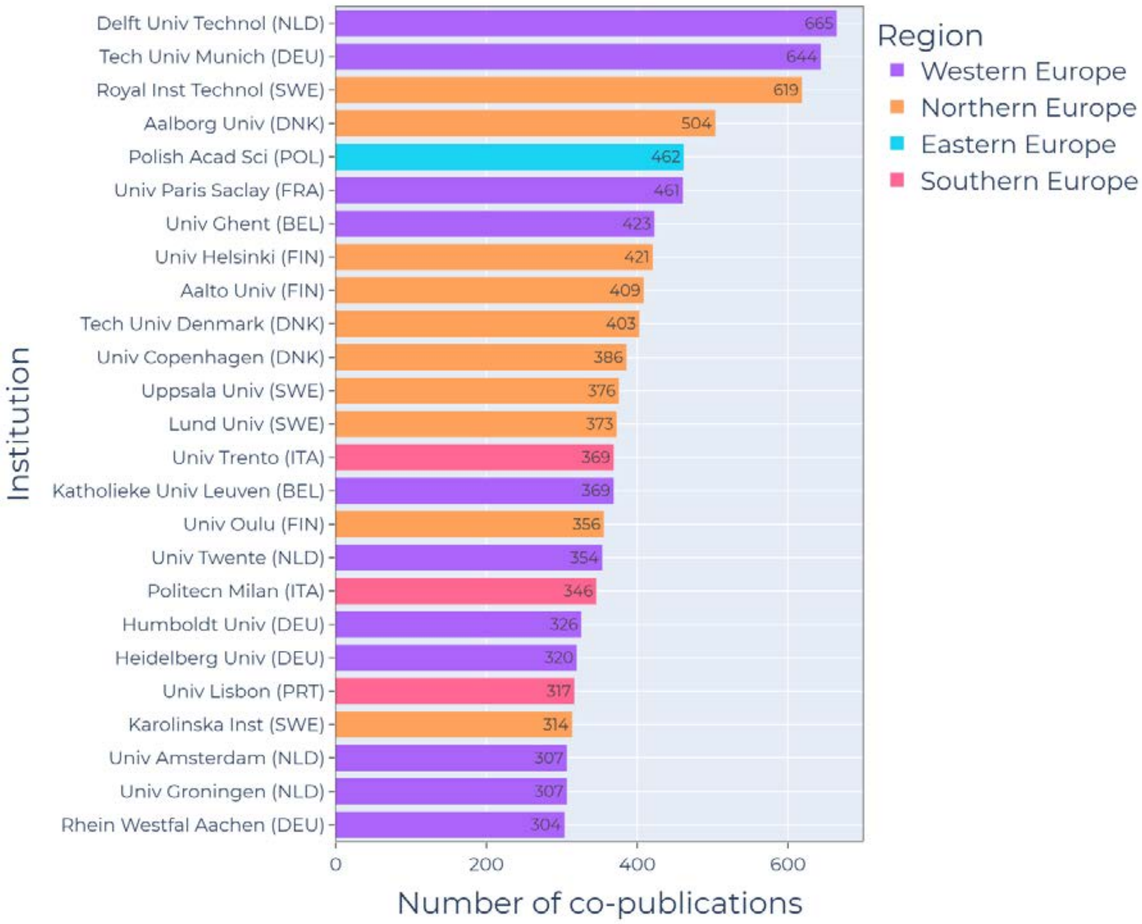


Figure 16. Top-25 most active institutions (only EU27 countries) countries) publishing on AI-related topics in collaboration with Chinese institutions

After discussing the EU27/AC institutions, we turn our attention to institutions involved from China. The first fact to note is the strong leadership position of the Chinese Academy of Sciences (CAS). It holds 4632 co-publications with EU27/AC counterparts, whereas the renowned Tsinghua University, second-ranked, holds “only” 1936. With that, CAS shares more than 10% of all Chinese co-publications with EU27/AC. The CAS co-publication performance dwarfs the performance of many leading Chinese universities, and this could indicate towards some major differences between the administration and functioning of the European and Chinese science systems. In the detailed analysis of scientific fields and subfields, there are some instances whose interpretation against these characteristics is conducive as well.

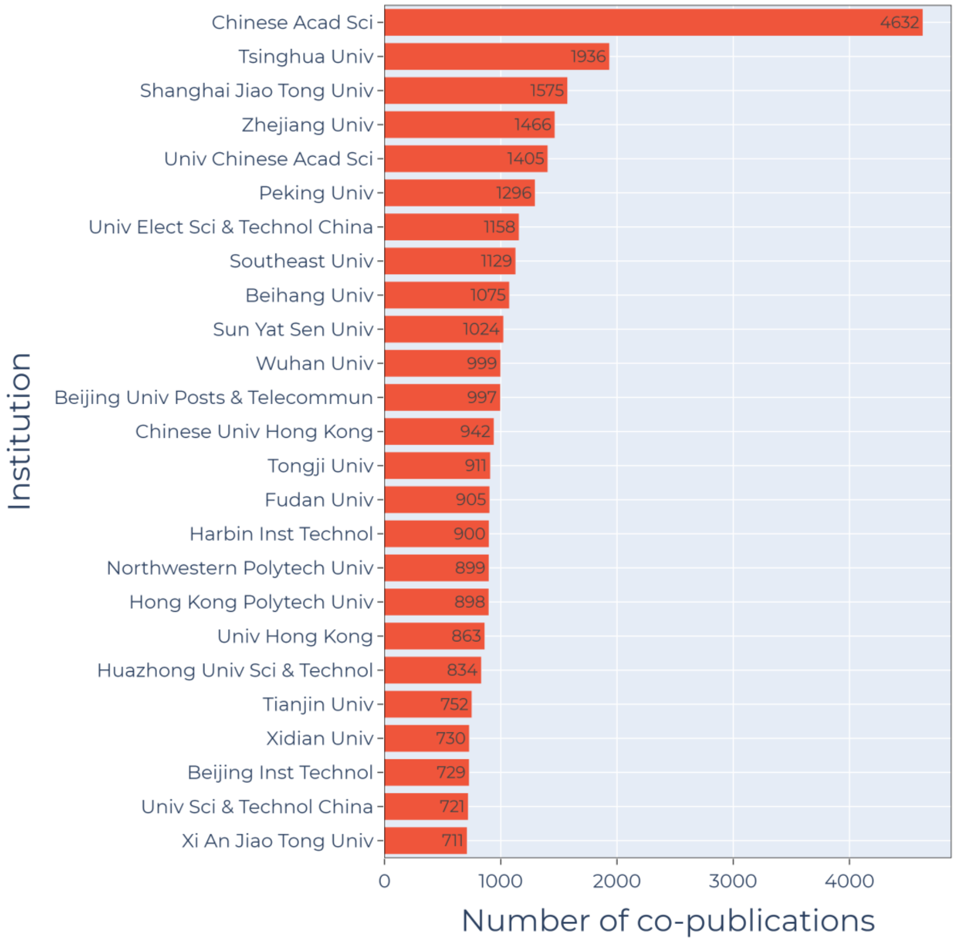


Figure 17. Top-25 most active Chinese institutions publishing on AI-related topics in collaboration with European institutions.

In the following, we use "collaboration matrices" that help us to chart a more nuanced understanding of institutional collaboration. With collaboration matrices we are able to summarise the total number of co-publications between any institutional pair with one European and one Chinese partner. Using two types of breakdowns, we provide some visualisations below. Figure 18 on the one hand unveils the most prolific collaboration patterns by pairing the top-25 institutions from both regions. Figure 19 on the other does the same, but without the accession countries. To read our collaboration matrices easier, the following rule applies: Institutions with the highest number of co-publications are always clustered in the upper left part of the matrix. In order to quickly identify any outlier cooperation patterns that may be connected to these leading institutions these cases are always contrasted in the lower left part.

Back to Figure 18, which caters to an analysis of general cooperation patterns between the most actively involved institutions on both sides. Some findings though deviate from the overall logic. As an example, Queen Mary University of London had a relatively high number (102) of co-publications with Beijing University of Posts & Telecommunications, albeit both institutions don't count to the forefront actors in overall collaboration patterns. It is also worth noting that there are relatively few co-publications between the Imperial College of London and the University of

Science and Technology of China (only 15), which contrasts the general trend of leading British universities which had at least 50 co-publications with their leading counterparts in China.

Both Figure 18 and Figure 19 show another apparently intensive collaboration pattern between Aalborg University (Denmark) and the University of Electronic Science and Technology of China (78 co-publications), which is different to the overall positioning of these two institutions. In Figure 19 we observe a specifically dynamic relationship both between the Technical University of Munich (Germany) and Tongji University (61) and Aalto University (Finland) and Xidian University (43). Finally, there are some European institutions that don't appear as leading institutions in overall records, despite being productive co-publishers in specific cases. We assume this has to do with their collaboration portfolio of partners, which is rather built on the quantity than the intensity of collaborations. This mainly concerns the University of Groningen (The Netherlands), Katholieke Universiteit Leuven (Belgium) and Politecnico Milano (Italy).

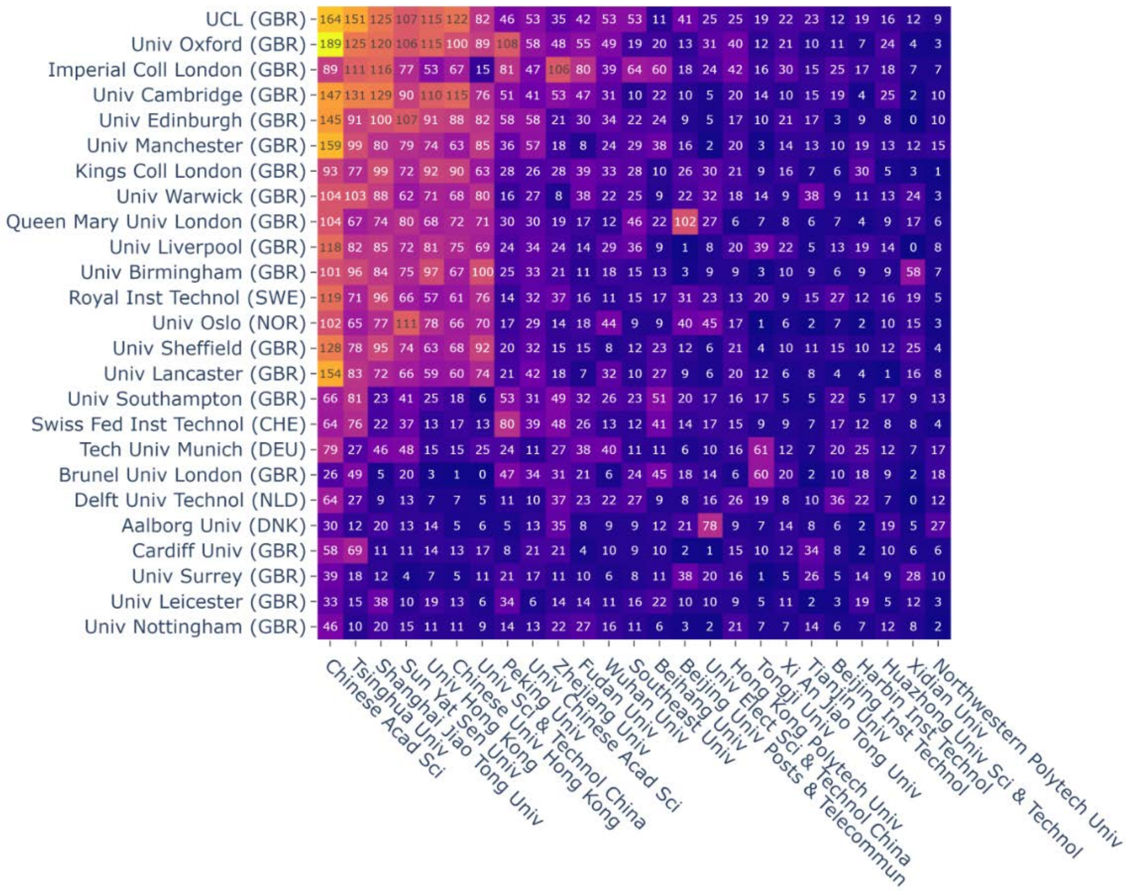


Figure 18. Collaboration patterns (number of co-publications) between the top-25 most active EU27/AC and Chinese institutions

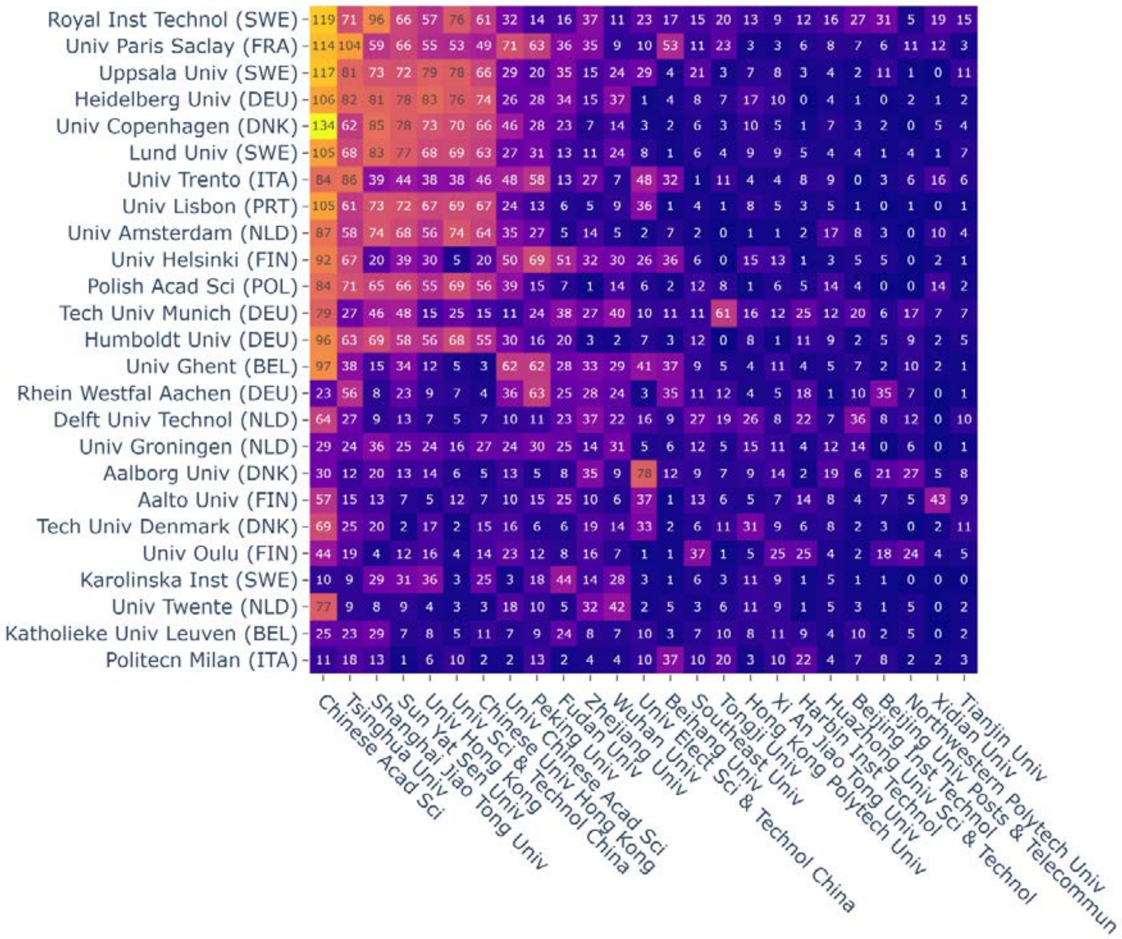


Figure 19. Collaboration patterns (number of co-publications) between the top-25 most active EU27 and Chinese institutions

4.1.5 Analysis of Applied Sciences

Figure 20 shows both the detailed distribution and developments of co-publications classified in the research domain of applied sciences. The most dominant research fields within this domain are Information & Communication Technologies (15.6k), Engineering (9.2k), and Enabling & Strategic Technologies (3.9k). This is likely biased by the original topic scope of our dataset, since “AI” is usually related to the Information Technology sector. Despite the comparably small number of co-publications in total, the field of Enabling & Strategic Design (long-term design principles in order to increase innovative and competitive qualities) became the fastest growing after 2018.

Figure 20. Detailed distribution of fields and respective tendencies of co-publications classified in the domain of Applied Sciences. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

The country-specific relative increases in co-publication outputs as in the following Figure 21 complement the overall picture of national contributions (Figure 11) with some additional insights. First of all, the most significant increases in collaboration patterns are observed in Poland and Hungary. The trends recorded in these two and some other countries like Slovakia, Cyprus, Greece, and Luxembourg lead to the conclusion of a sudden co-publication boom starting in the mid-2010s. On the contrary, France and larger Western European countries show a comparatively stagnant, or low-growth trend.

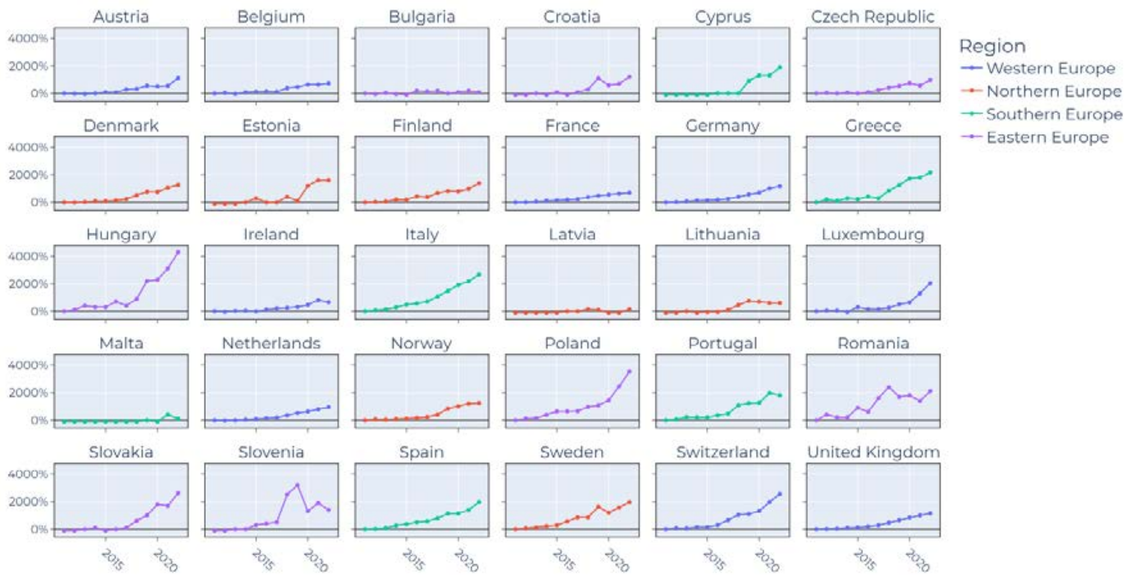


Figure 21. Relative growth at country level of annual scientific output (indexed to 2011) of co-publications in the domain of Applied Sciences.

The 15 most active EU27 institutions jointly publishing with China in Applied Sciences are shown in Figure 22. Here we note that the surprisingly high contribution of the Polish Academy of Sciences (previously on Figure 16) can be largely attributed to its efforts within this specific category and explains the relatively high growth of Polish co-publications (Applied Sciences: 55%, Natural Sciences: 27%, Health Sciences 15%; Other 3%, 1442 co-publications in Poland overall).

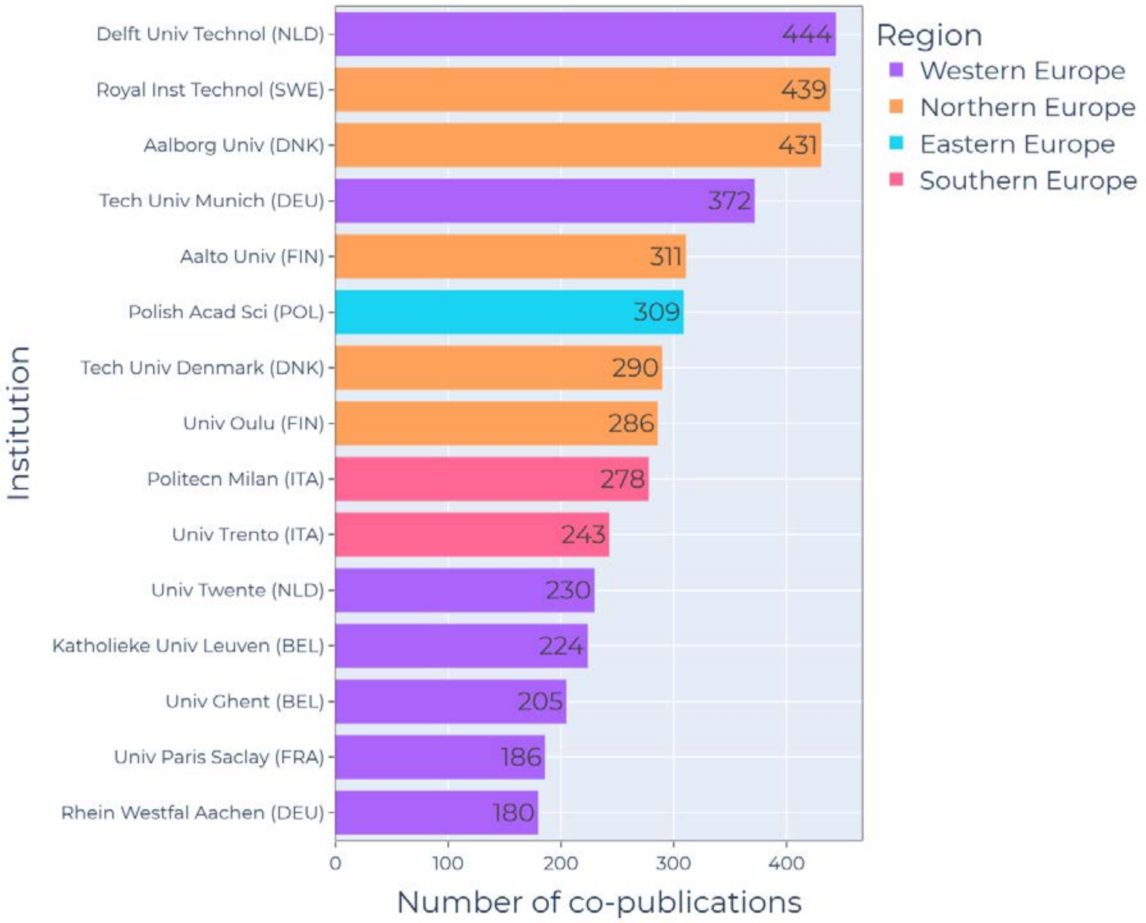


Figure 22. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the domain of Applied Sciences

4.1.6 Analysis of Natural Sciences

In Natural Sciences, the research fields are relatively even distributed (Figure 23). However, with Physics & Astronomy there is still a dominating field (3113). This is not surprising, as Physics & Astronomy generally is a data-intensive field, relying heavily on various AI-related methods, such as image processing, clustering and classification of algorithms, or any other similar machine learning applications. The same can be said for Earth & Environmental Sciences, where satellite imagery and sensor data analysis are standard research approaches. Rather surprising to us is the number of co-publications in Mathematics & Statistics. Given the enormous theoretical contributions of this research field to very important topics for the advancement of AI technologies like machine learning. Looking at the relative growth of fields, we note the surge of publications in

Chemistry (red line), along with continuing developments in Earth & Environmental Sciences, which has roughly grown 13x in scientific outputs during the observed period.

Figure 23. Detailed distribution of fields and respective tendencies of co-publications classified in the domain of Natural Sciences. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

Figure 24 digs again into the co-publishing activities of the EU27/AC. Ireland shows an exceptionally high growth (an almost 50-fold increase in co-publications per year; this is likely due to its initial low co-publication output in 2011; only a single co-publication), thus further research to understand better the backgrounds of these results would be warranted. Most other countries do not show remarkable trends.

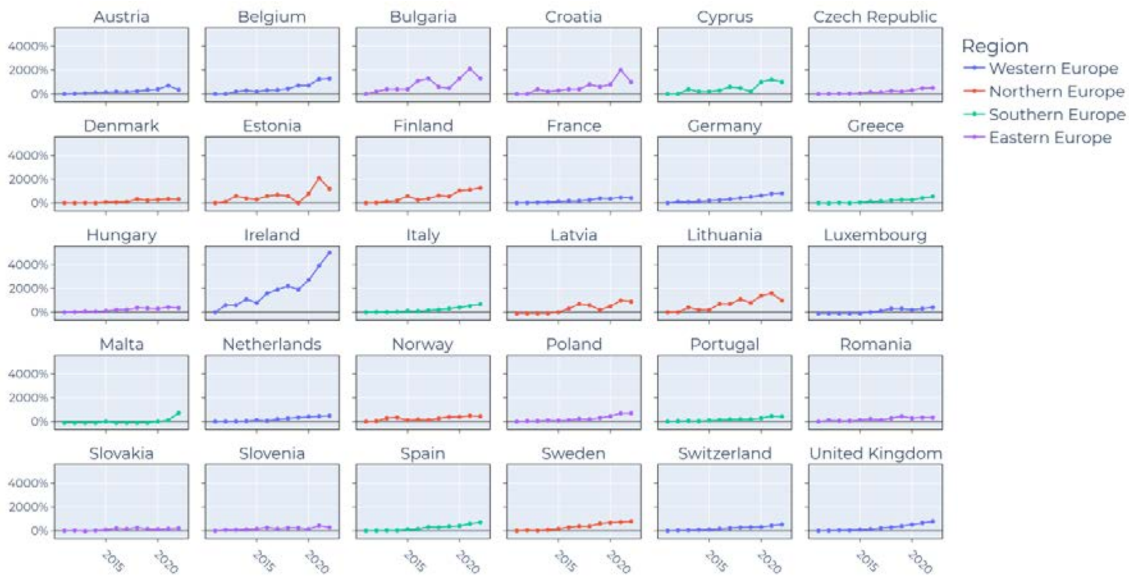


Figure 24. Relative growth at country level of annual scientific output (indexed to 2011) of co-publications in the domain of Natural Sciences.

As for Applied Sciences, we were interested in the most active EU27 institutions in terms of co-publishing with China (Figure 25). It appears that Charles University of Prague is the only Eastern European institution among the top-15 co-publishers.

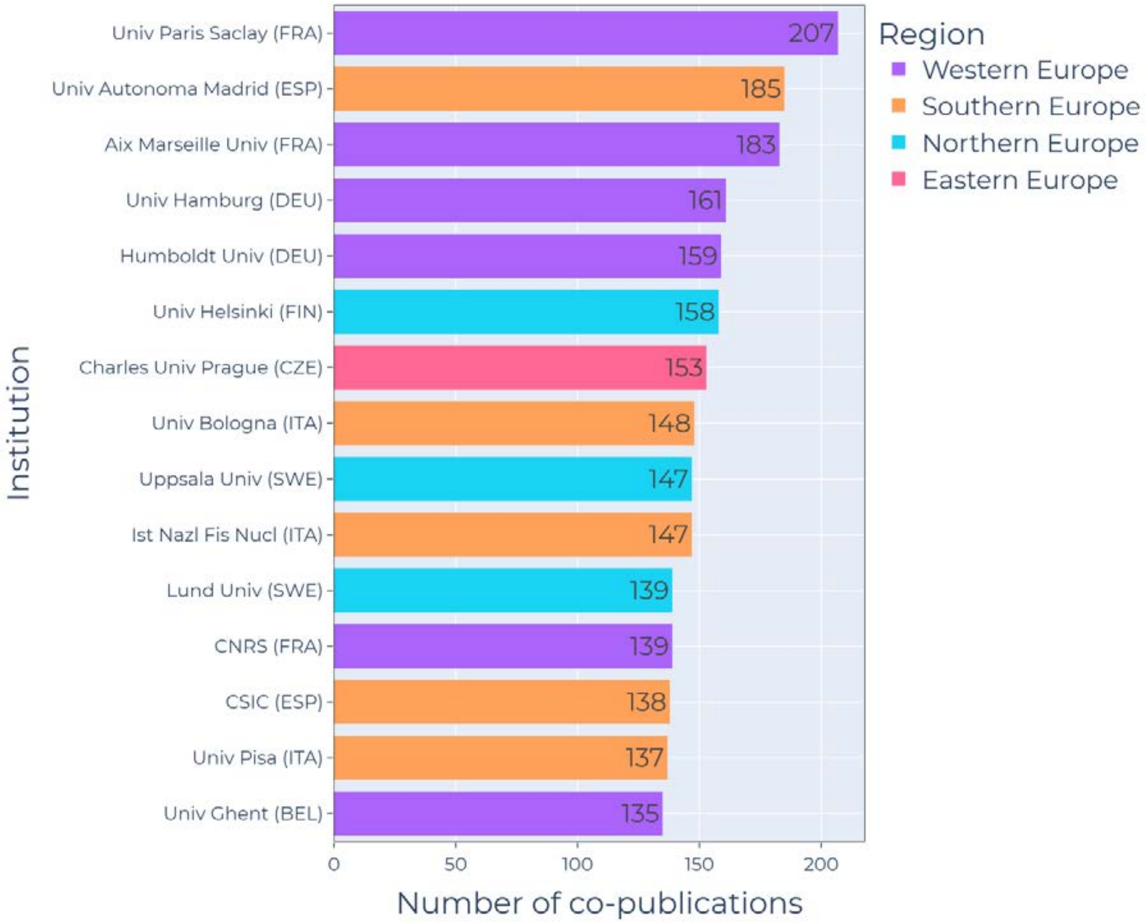


Figure 25. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the domain of Natural Sciences

4.1.7 Analysis of Health Sciences

In Health Sciences, the field of Clinical Medicine is leading the ranking with ~3.4k co-publications (Figure 26). Biomedical Research follows with ~1k. In terms of trends (relative growth of co-publications), Public Health & Health Services (purple line) was least growing in the period analysed, while Psychology & Cognitive Sciences and the two fields mentioned above increased their co-publication share by 10-12 times over the last 11 years.

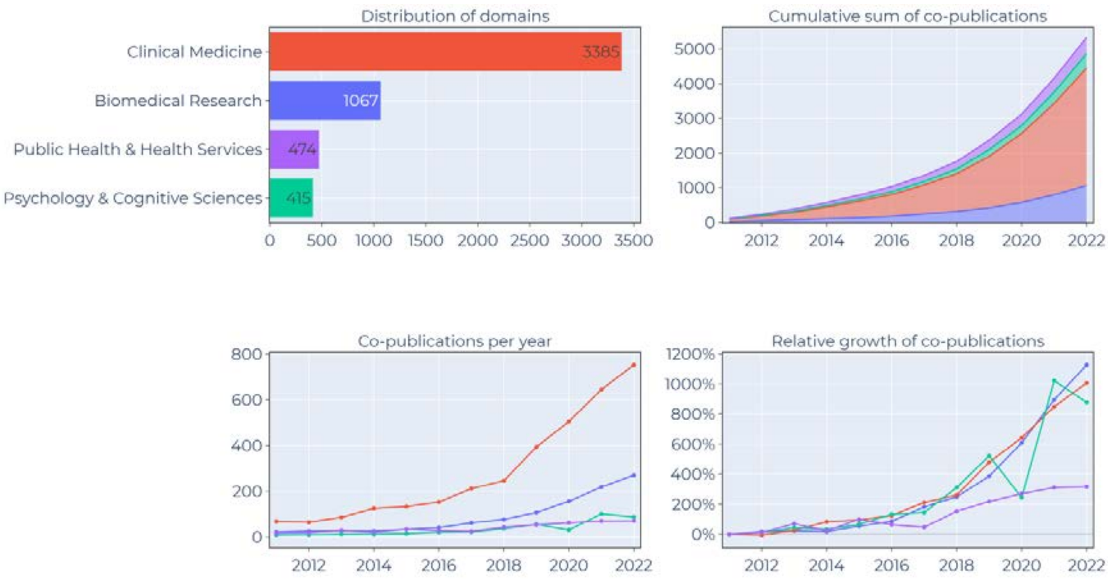


Figure 26. Detailed distribution of fields and respective tendencies of co-publications classified in the domain of Health Sciences. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

Figure 27 presents results on the country level again. The raise of co-publications with China in some countries, in particular Austria, Czech Republic, Ireland, Poland, and Portugal, was remarkable (between 20-40x higher between 2011 and 2022) For Ireland, Austria, and the Czech Republic the strong increase commencing with the year 2017 is worth to note.

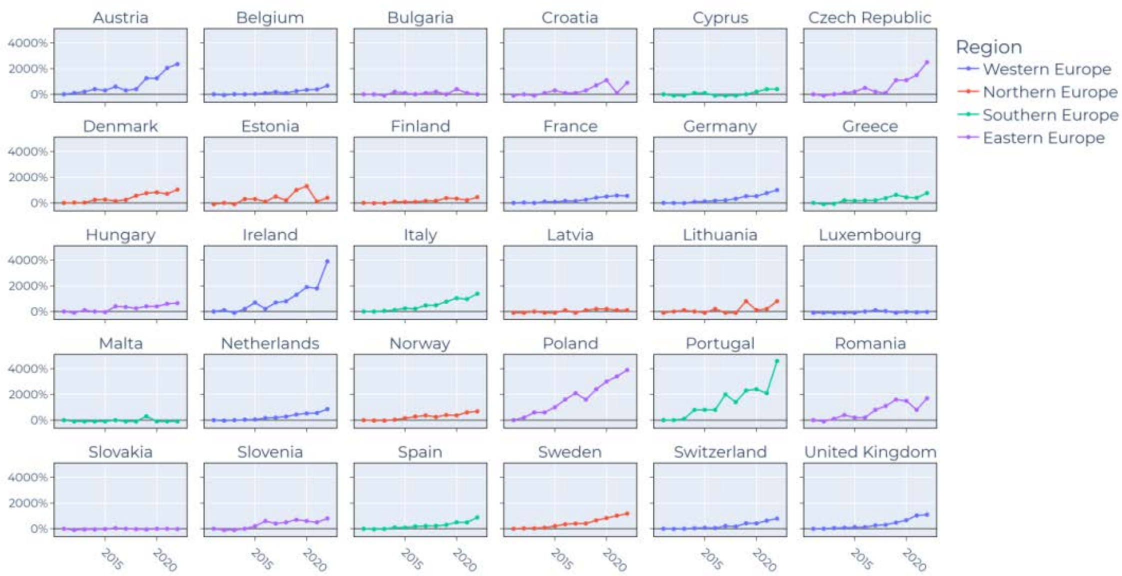


Figure 27. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the domain of Health Sciences.

In Health Sciences we did an additional extraction of Chinese institutions involved in these collaboration networks (Figure 28). Contrary to the results presented earlier in this report on the overall contribution of Chinese institutions (Figure 17), the CAS appears as a relatively unimportant player in the Health Sciences, while every other scientific field previously dissected is dominated by CAS. In Health Sciences, Peking University jointly with Chinese University Hong Kong leads the field (352 co-publications each).

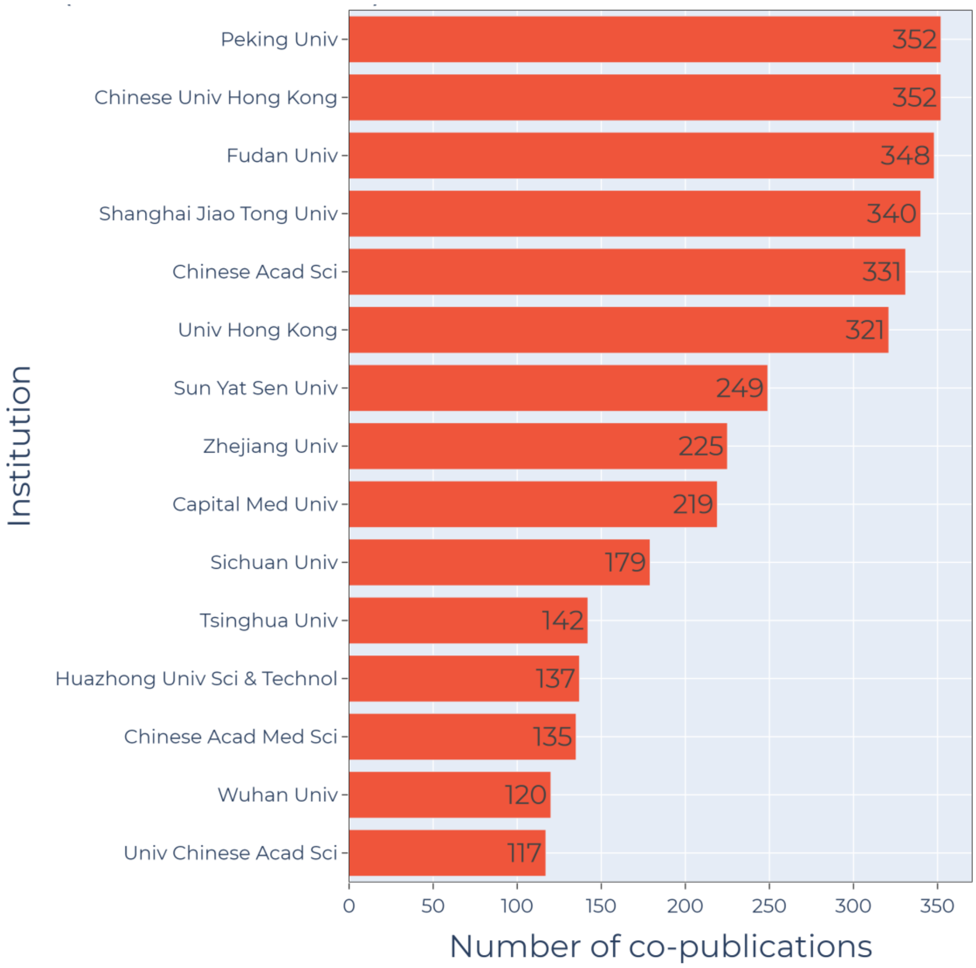


Figure 28. Top-15 most active Chinese institutions publishing with European authors within the domain of Health Sciences.

Among EU27 institutions (Figure 29), the Karolinska Institute in Sweden is the co-publication leader in Health Sciences (273). Technical University of Munich, University of Groningen and Heidelberg University are following with only very a very small span between each other. If we would add institutions from the associated countries UK, CH and NO to this overview (figure not shown), Karolinska Institute as the first actor from a non-associated country would reach the third place, and still ahead of University College London (296) and Oxford University (275). Not surprisingly, the top-15 EU27 institutions hail from countries renowned for their advanced healthcare research infrastructure, and innovation in medical sciences: Sweden, the Netherlands, Germany, Denmark, and Austria.

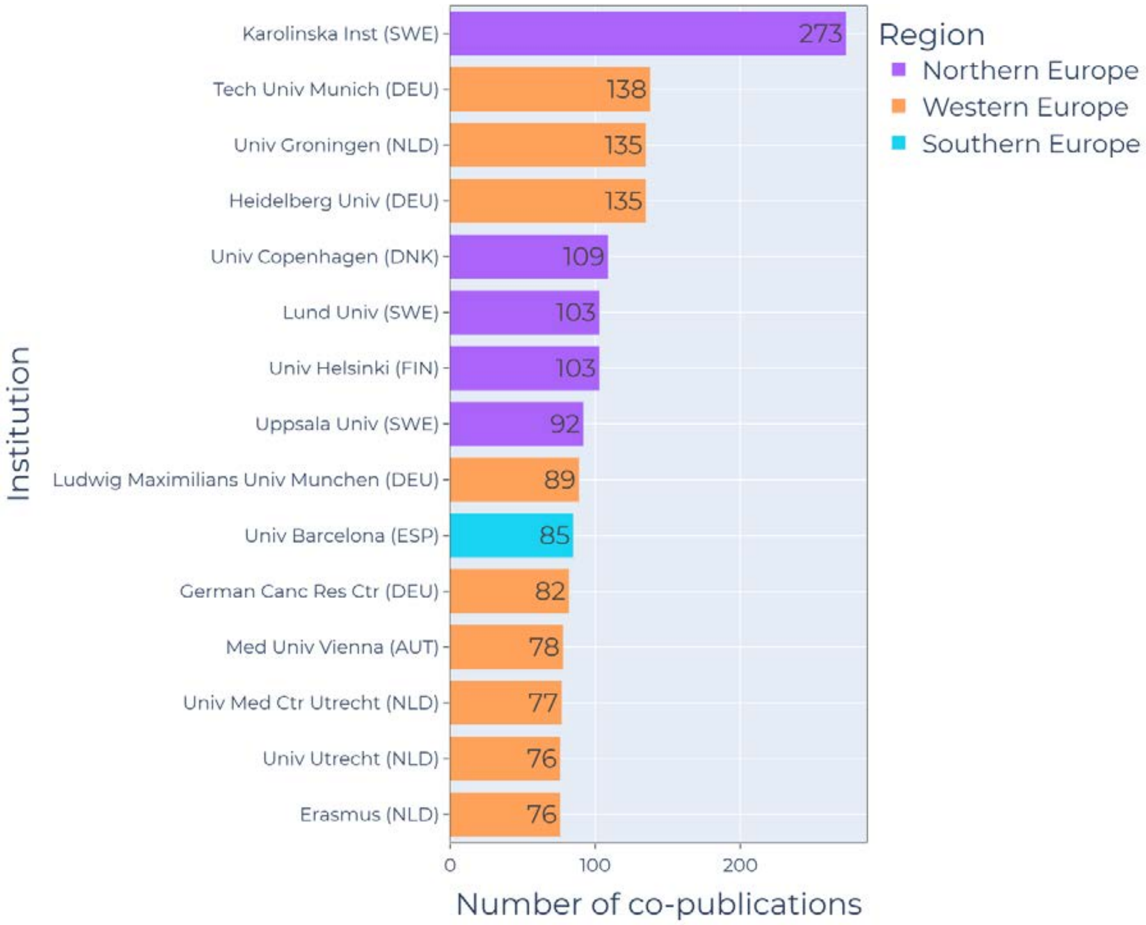


Figure 29. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the domain of Health Sciences

4.1.8 Analysis of Economic & Social Sciences

Within the domain of Economic & Social Sciences, a general strong focus on the research field of Economics & Business can be observed (almost ~30-fold raise in co-publication numbers). Social sciences on the other hand was growing in terms of total numbers of co-publications, but from a much lower volume. (Figure 30)

Low representation subfields (<50 co-publications) within this domain:

Economics & Business:

1. Accounting: 3 publications
2. Agricultural Economics & Policy: 3 publications
3. Development Studies: 4 publications
4. Economic Theory: 2 publications
5. Industrial Relations: 4 publications

Social Sciences:

1. Anthropology: 1 publication

2. Criminology: 8 publications
3. Cultural Studies: 2 publications
4. Demography: 5 publications
5. Gender Studies: 2 publications
6. International Relations: 3 publications
7. Law: 6 publications
8. Political Science & Public Administration: 8 publications
9. Social Sciences Methods: 15 publications
10. Social Work: 2 publications
11. Sociology: 2 publications

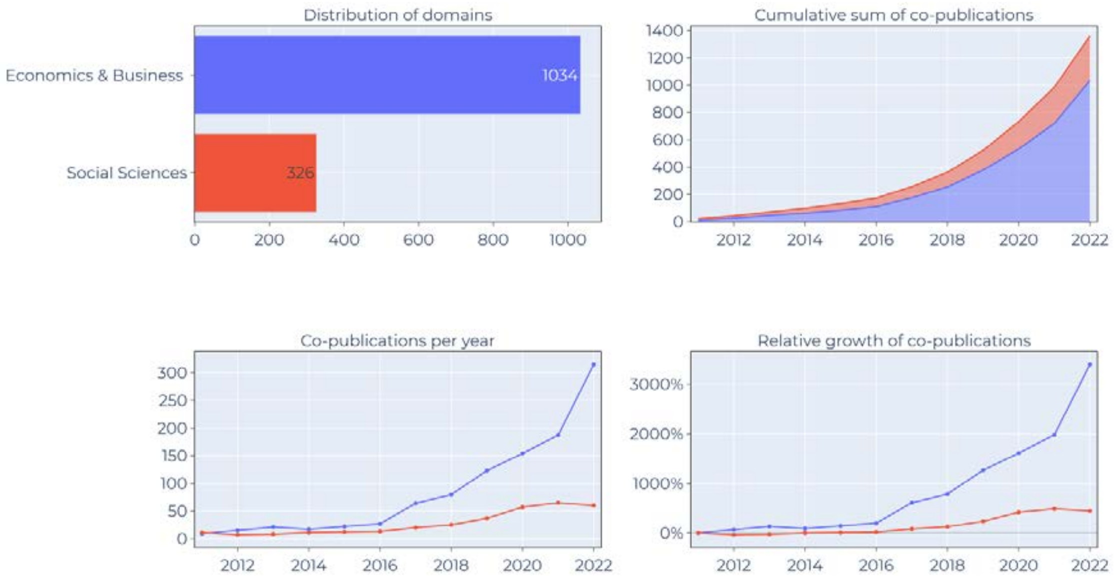


Figure 30. Detailed distribution of fields and respective tendencies of co-publications classified in the domain of Economic & Social Sciences. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

Figure 31 shows the relative increase of co-publications by country. France experienced a drastic surge in its co-publications with China (numbers increased by a factor of 40), over the last three years. This may have to do with the United Kingdom's Brexit which officially took effect on January 31, 2020, triggering consequences also in the world of sciences with an EU-orchestrated global research and innovation approach, which was shaped and implemented without UK participation henceforth. Finland, Spain and Sweden experienced an increase alike, though with somewhat smaller numbers (20 times more co-publications from 2011 to 2022).

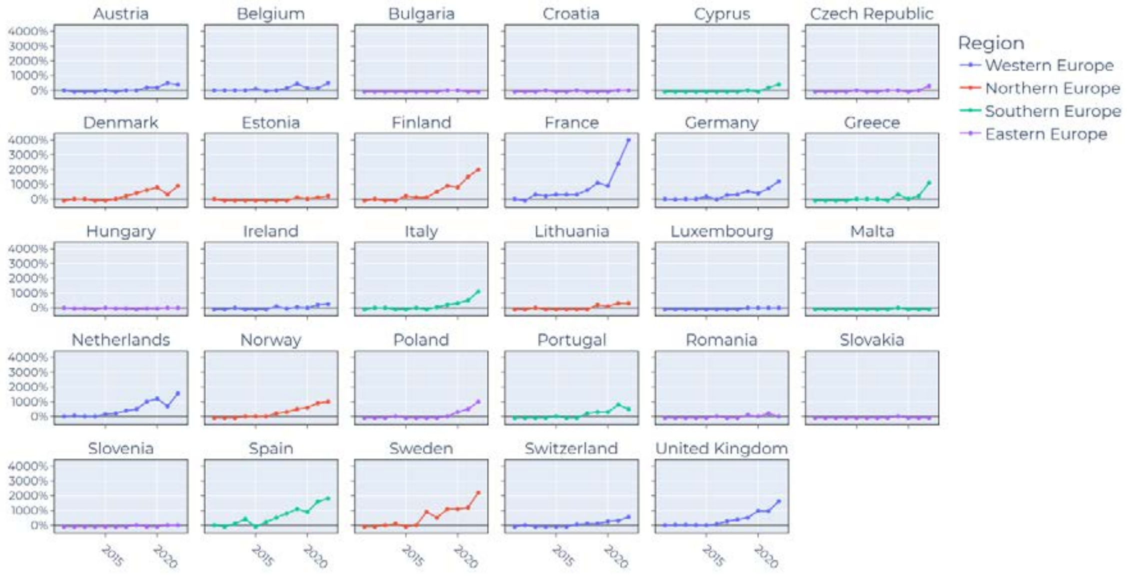


Figure 31. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the domain of Economic & Social Sciences.

On the Chinese side, the Hong Kong Polytechnic University holds most co-publications. The Chinese Academy of Sciences is second this time. We also take note of Beijing's presence in this specific analysis, as five of the 15 most active Chinese institutions publishing in Economic & Social Sciences with their European counterparts are located in the capital city (Figure 32).

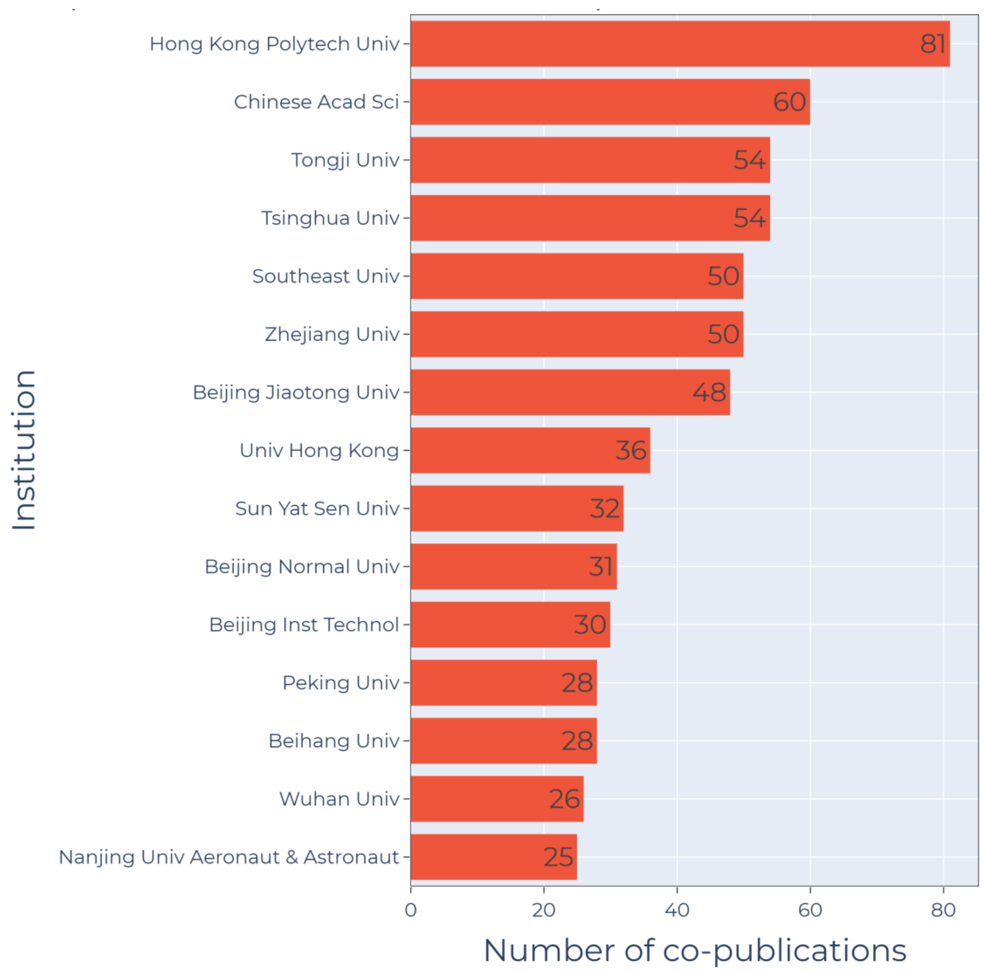


Figure 32. Top-15 most active Chinese institutions publishing with European authors within the domain of Economic & Social Sciences.

Figure 33 shows the top-15 institutions from the EU27. Generally speaking, the Western and Northern European institutions dominate the field, headed by Delft University of Technology from the Netherlands (51 joint publications with Chinese partners).

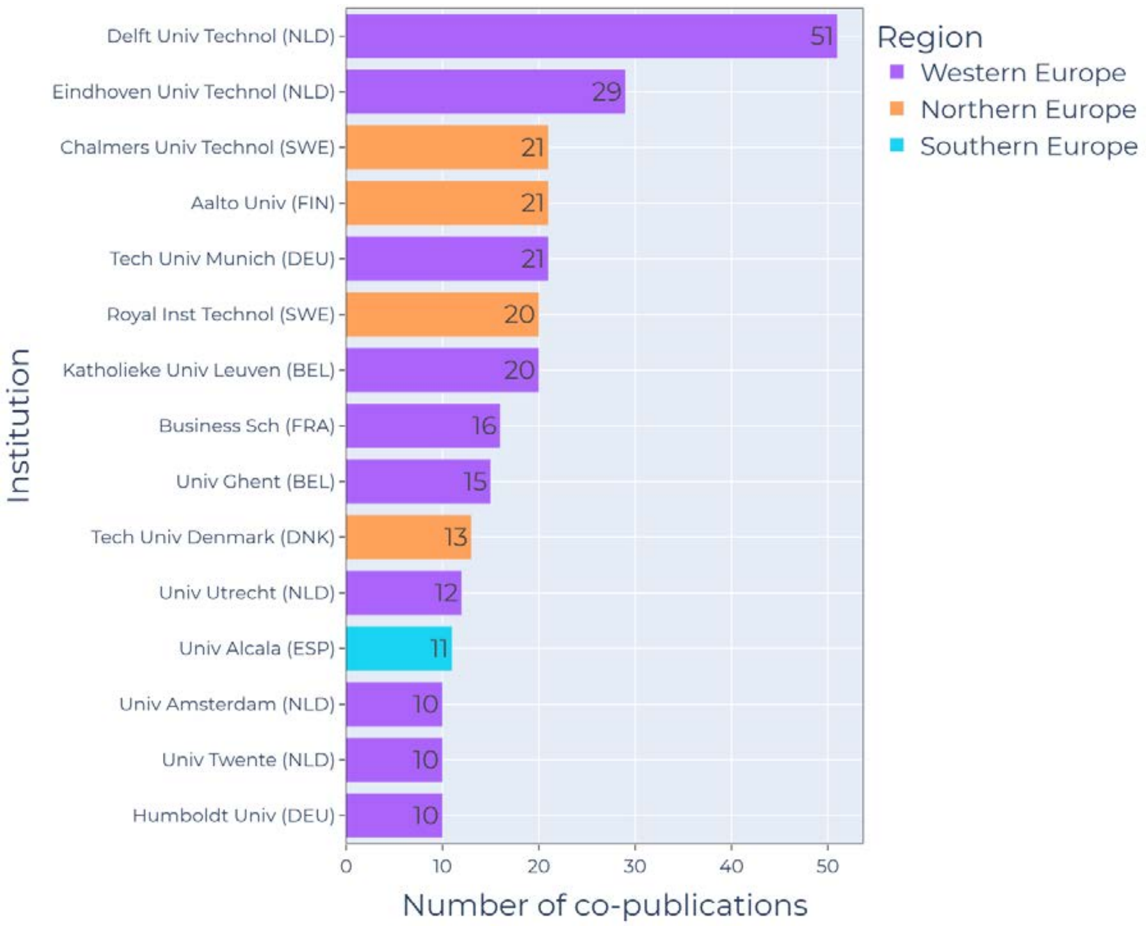
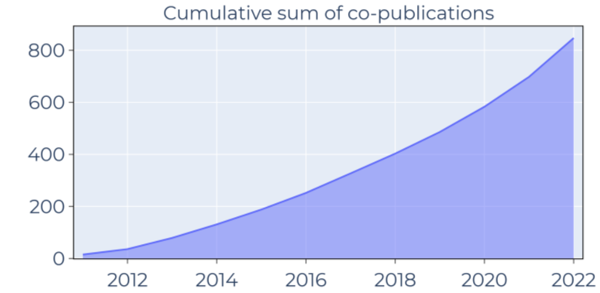


Figure 33. Top-15 most active collaborating institutions from EU27 publishing with Chinese authors within the domain of Economic & Social Sciences

4.1.9 Analysis of "Multidisciplinary"

While a detailed impact analysis is beyond the scope of this report (check the Methods section for more details), it is worth focusing on the multidisciplinary domain of co-publications as a countermeasure. In the Science Metrix ontology, several prestigious journals belong to this domain, such as *Nature*, *Science*, *Science Communications*, *PNAS* and *PloS ONE*. Although the output number of this domain is overall low (a total of 847 co-publications only between 2011-2022), the high impact factor of the mentioned renowned journals compensates for the importance of this category of papers.

Figure 34 shows the general trends of multidisciplinary co-publications. While the 2010s were characterised by a slow increase of co-publications, their number increased progressively over the last three years (2020, 2021, 2022). In sum, the volume of multidisciplinary co-publications raised 8 times between 2011 and 2022, which is still the lowest growth rate of all research domains within this analysis.



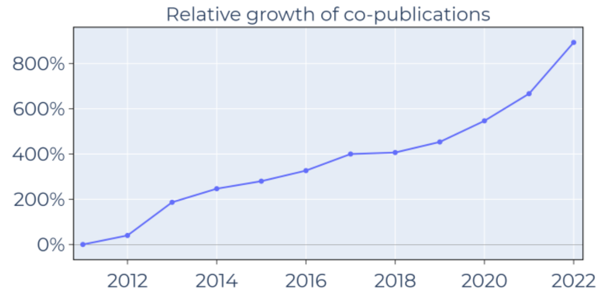


Figure 34. Trends of co-publications classified as Multidisciplinary. Cumulative sum of co-publications and relative growth in annual scholarly output of co-publications, indexed to 2011.

On the European side, we note only a few countries with significant dynamics in their output rate (Figure 35). Eastern European countries, generally speaking, don't really appear in these cooperation networks. The strongest relative increases can be observed in Western and Southern European countries.

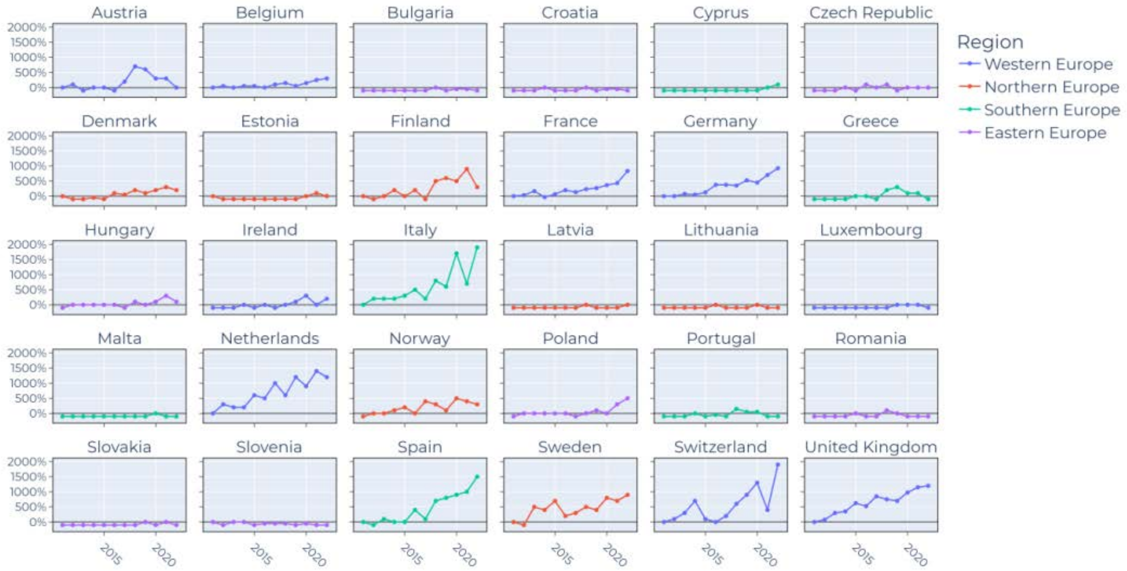


Figure 35. Relative growth at country level of annual scholarly output (indexed to 2011) of Multidisciplinary co-publications.

On the Chinese side, most prolific institutions are affiliated to the Chinese Academy of Sciences (figure not shown). On the EU27 side, the most active institutions are from Northern and Western Europe, with a relatively even distribution between the top-4 (Figure 36). If we would add institutions from the AC to this overview (figure not shown), University of Copenhagen as the first EU27-institution would only come 5th. University of Oxford (40), University of Cambridge (34).University College of London (30) and Swiss Federal Institute of Technology (23) are the leaders in this combined analysis.

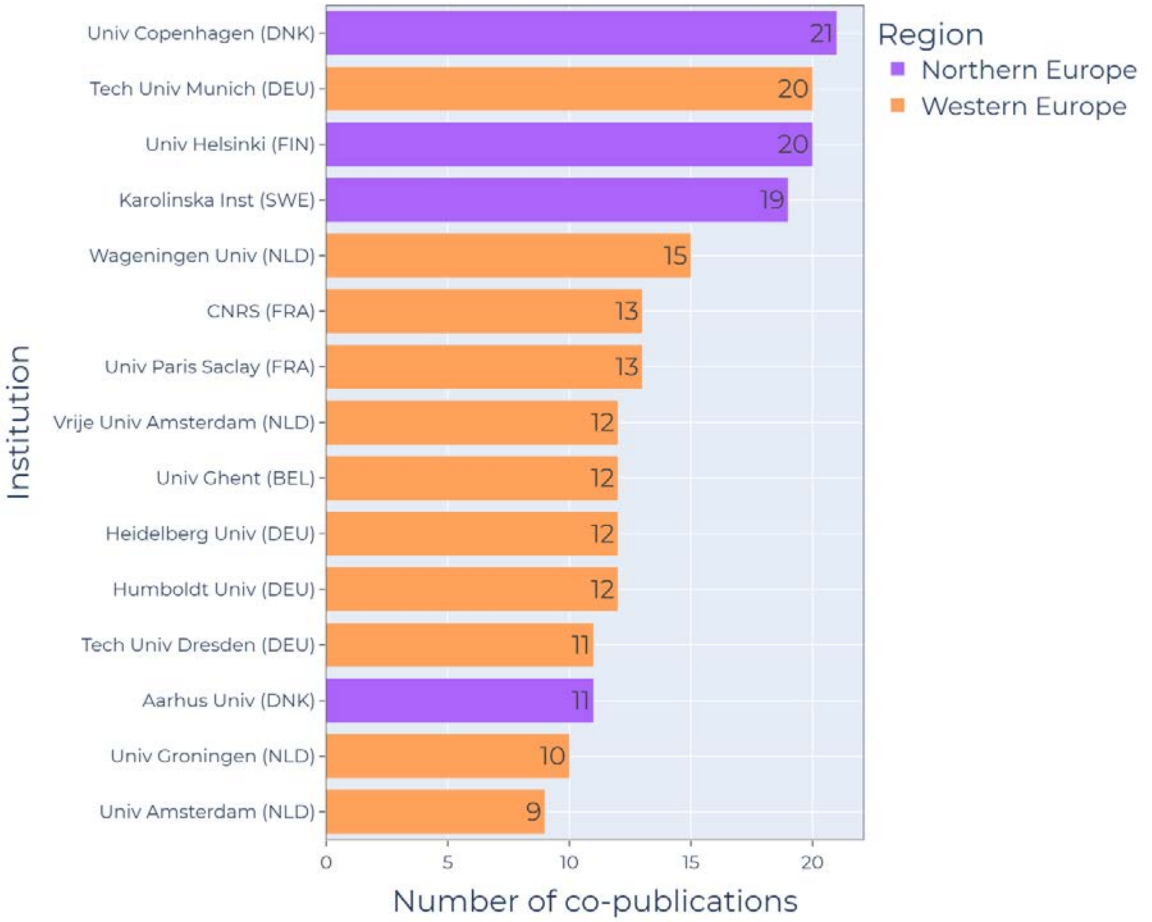


Figure 36. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors in Multidisciplinary journals

4.1.10 Trending and most significant subfields

During our analysis, we identified several subfields that either exhibited a notable increase in co-publications or garnered a significant proportion of co-publications relative to other subfields within the same scientific category. These include:

- AI & Image Processing
- Networking & Telecommunications
- Geological & Geomatics Engineering
- Industrial Engineering & Automation
- Electrical & Electronic Engineering
- Energy

- Analytical Chemistry
- Distributed Computing
- Nanoscience & Nanotechnology
- In the following chapter, we discuss the key insight gathered from our analysis on trending and most significant research subfields.

4.1.10.1 AI & Image Processing

The high representation of entries related to this subfield (17% of co-publications fall into this category) has to do with the fact that the initial keywords of the WOS search query were aligned to this specific topic. This subfield is clearly biased towards British co-publications (Figure 37) with more than half of the records found belonging to the UK (compared to the overall ~40%; *cf.* Figure 11). None of the other countries reaches a 10% share of co-publications.

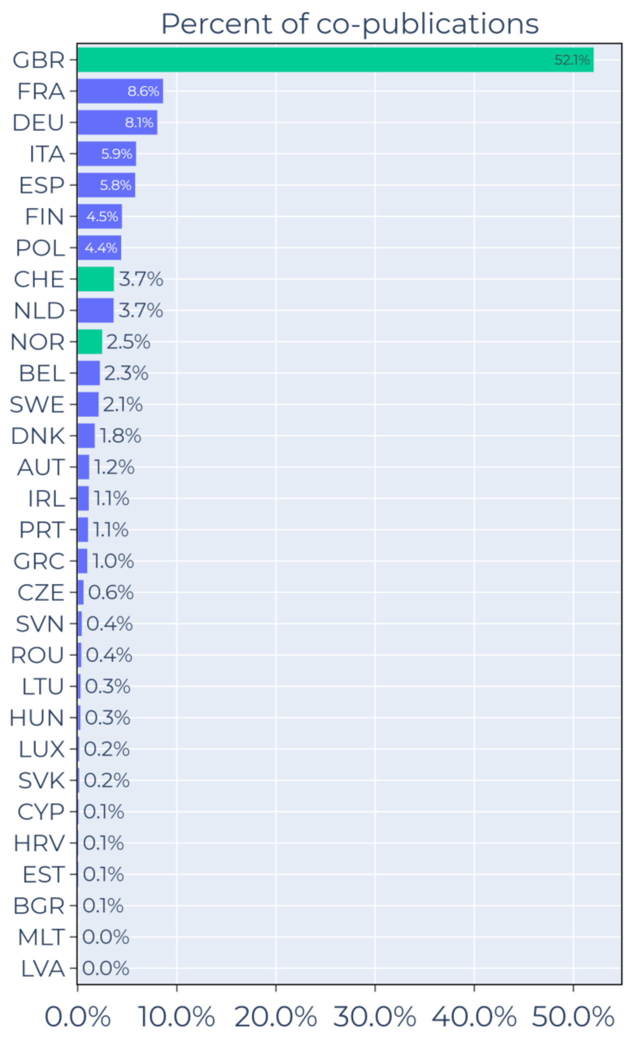


Figure 37. Contribution of EU27/AC countries to co-publications in journals classified in the subfield of AI & Image Processing

Looking at the relative growth of co-publications by country, Italy shows a more than 40-fold increase in output, and also Switzerland, Sweden and Poland have multiplied their output by 20. (Figure 38)

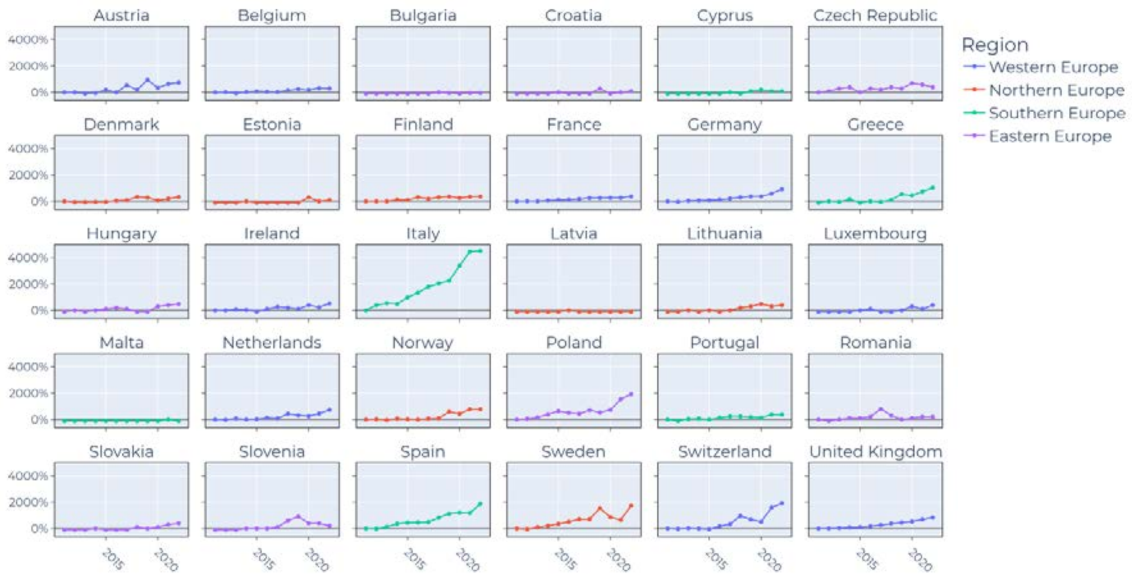


Figure 38. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the AI & Image Processing subfield.

Regarding institutions, the most active publishers are larger British universities (figure not shown). Without institutions from accession countries the Polish Academy of Sciences leads the field of the EU27. The Academy's output (216 co-publications) is higher than that of some renowned UK institutions (University College London: 165; University of Oxford: 160). We also take note of the existing collaboration between the Chinese National University of Defense Technology, which is directly affiliated to China's Central Military Commission, and the Polish Academy of Sciences on the one (14), and the University of Oulu in Finland on the other hand (30) (Figure 39).

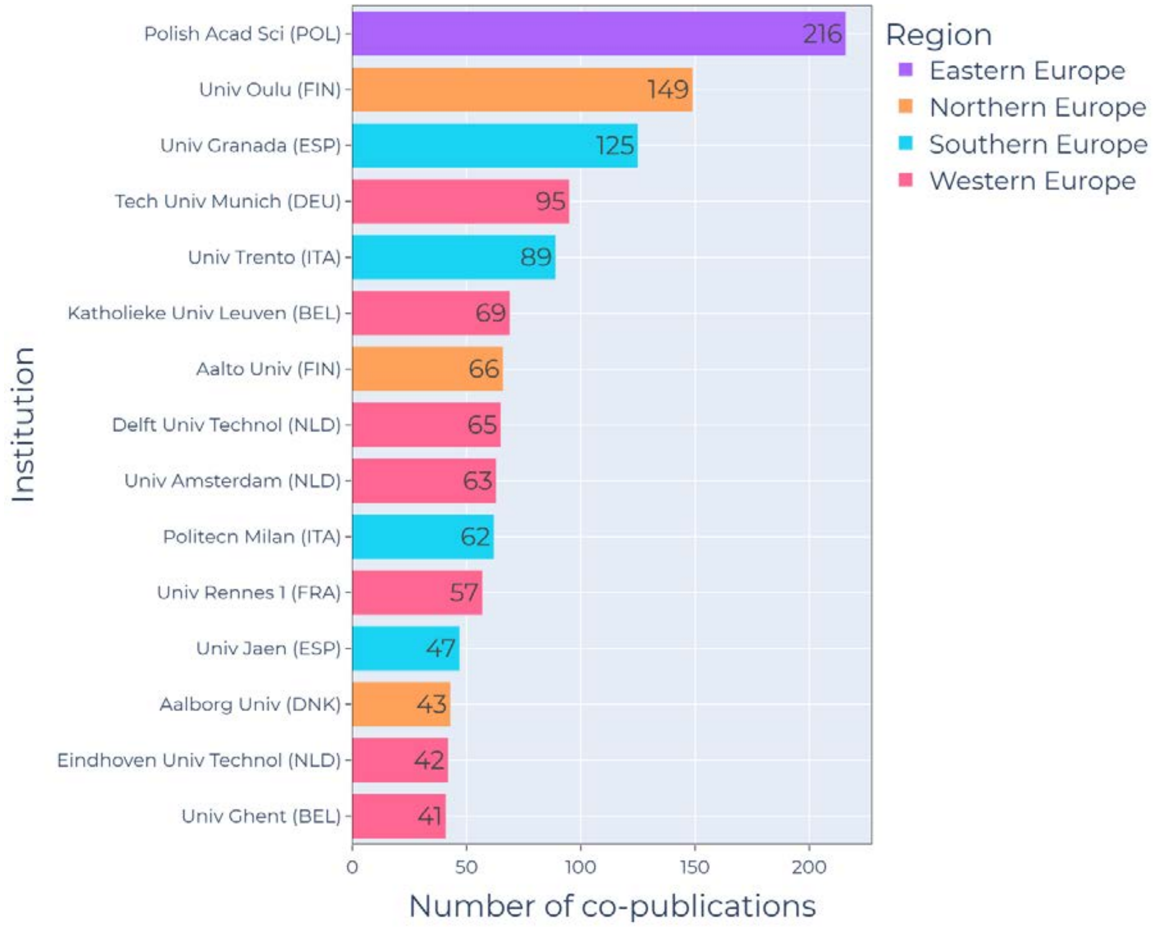


Figure 39. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of AI & Image Processing.

Some of the most prominent collaborations:

- University College London – Tsinghua University (40 co-publications)
- University of Birmingham – Xidian University (35 co-publications)
- University of Oulu (Finland) – National University of Defense Technology (30 co-publications)

4.1.10.2 Networking & Telecommunications

Co-publications in this subfield constitute 12% of all AI/ML/Big Data related EU27/AC-China co-publications. For Networking and Telecommunications there has been a huge relative growth in Finland (60-fold increase in output), whereas other countries like France, Germany, Norway, Sweden or the United Kingdom have experienced stagnating or declining rates of co-publications, in particular in recent years. (Figure 40)

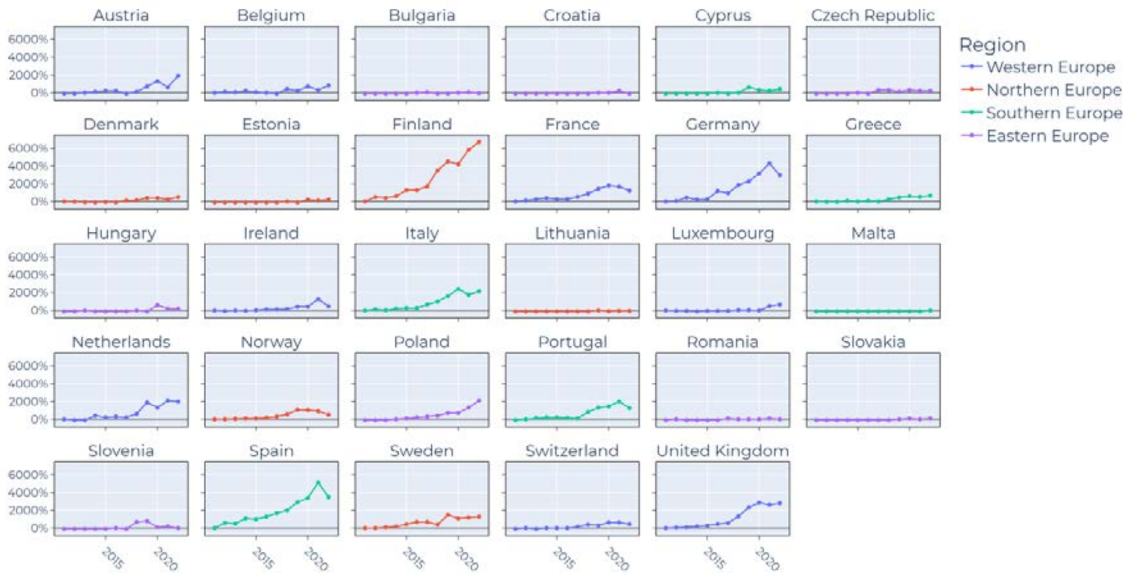


Figure 40. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Networking & Telecommunications.

The mentioned growth rate in Finland translates to a strong positioning of national institutions as well. Aalto University and the University of Oulu lead the field (Figure 41). Interestingly, Aalto and Oulu have relatively few co-publications with the leading Chinese institution, the Beijing University of Posts and Telecommunications (figure not shown). Thus, it can be assumed that their collaboration networks are of a more diverse nature.

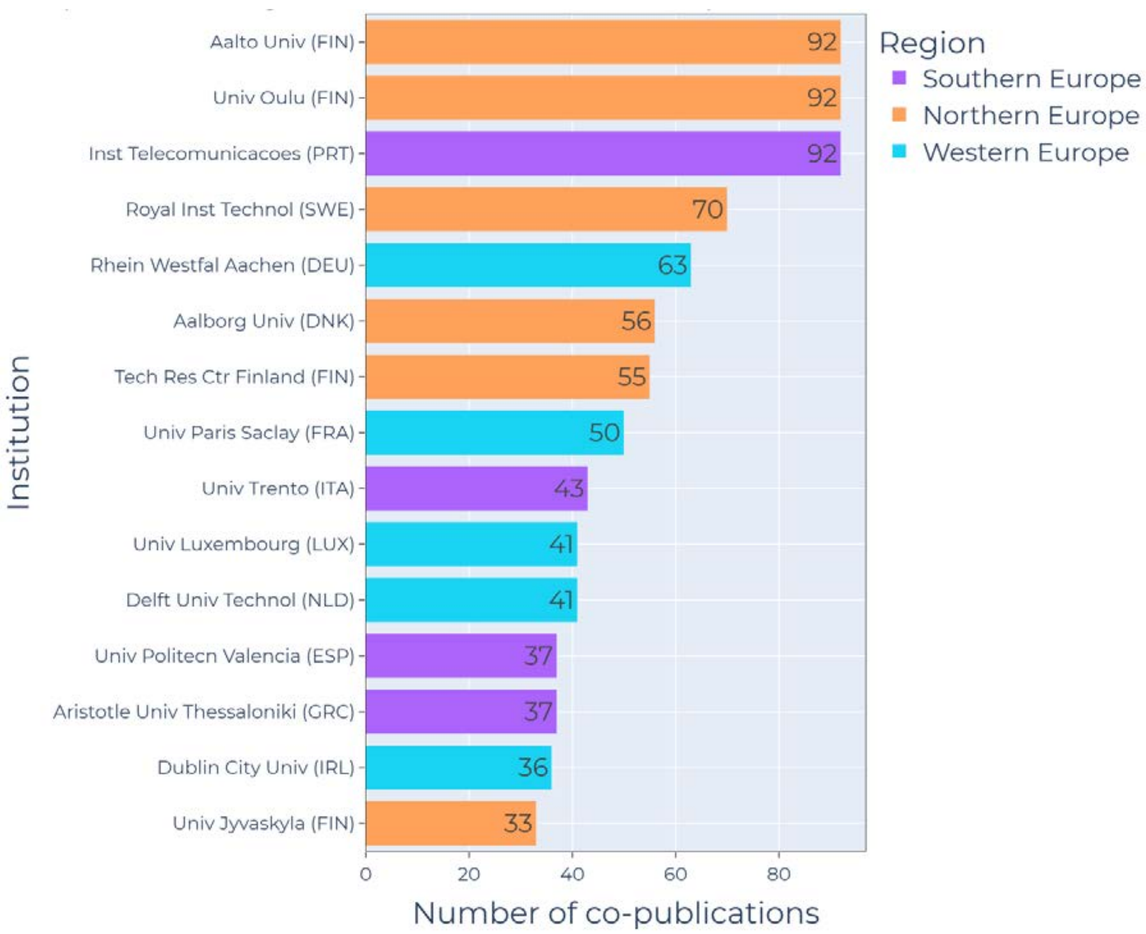


Figure 41. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of Networking & Telecommunications.

Some of the most prominent collaborations:

- Queen Mary University of London – Beijing University of Posts and Telecommunication (82 co-publications)
- University of Essex – University of Electronic Science and Technology (39 co-publications)
- University of Oslo – University of Electronic Science and Technology (35 co-publications)

4.1.10.3 Geological & Geomatics Engineering

Between 2011 and 2022 there have been 2576 co-publications (~6% of all co-publications) within the subfield of Geological & Geomatics Engineering according to our analysis of WoS data. The UK's contribution to this field is much less explicit than in general (Figure 42). Spanish co-publications increased in numbers 80 times, co-publications from Italy, Germany and, to a lesser extent, Austria by 40 times (Figure 43).

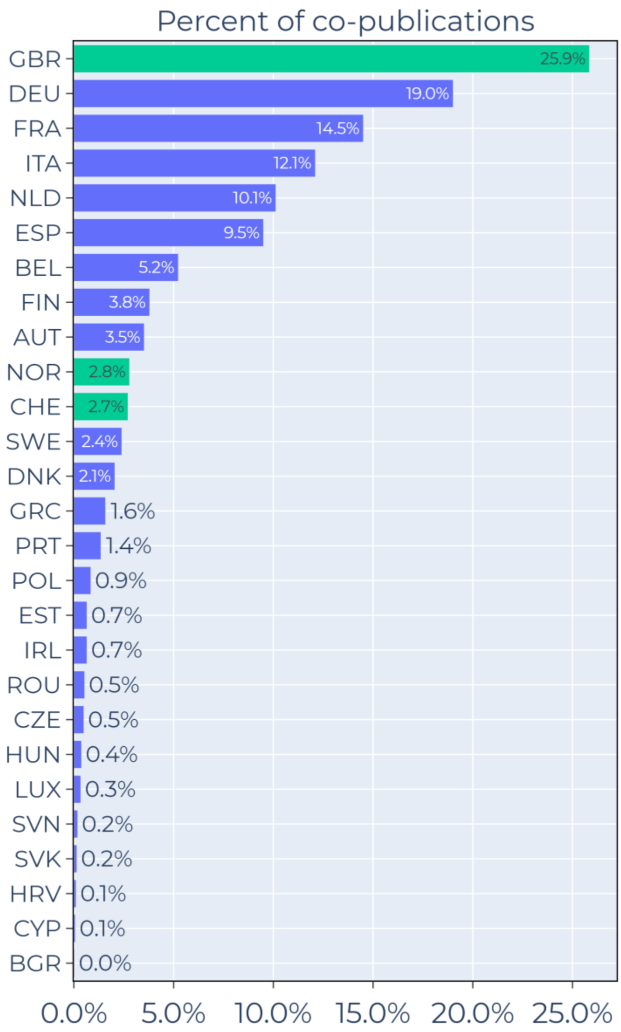


Figure 42. Contribution of EU27/AC countries to co-publications in journals classified in the subfield of Geological & Geomatics Engineering

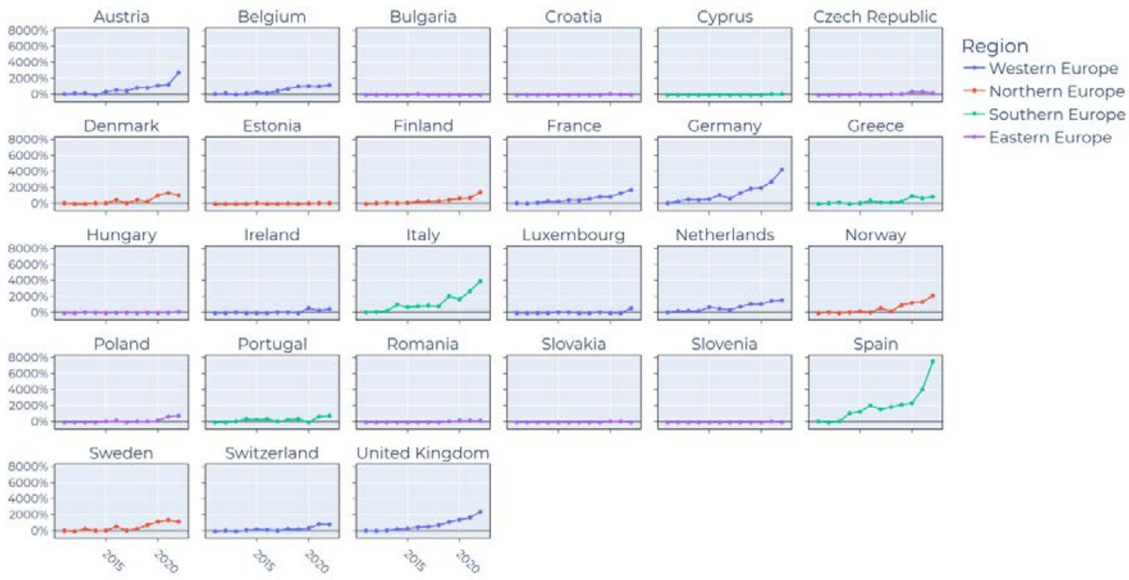


Figure 43. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Geological & Geomatics Engineering.

These findings reverberate also on the institutional level for the EU27 (Figure 44). In fact, the number of co-publications of the top-5 institutions from Spain, the Netherlands, Germany and France are higher than those of most British universities. The leading institution from EU27, the University of Extremadura, had a particular high level of collaboration with China's Sun Yat-sen University (57 co-publications).

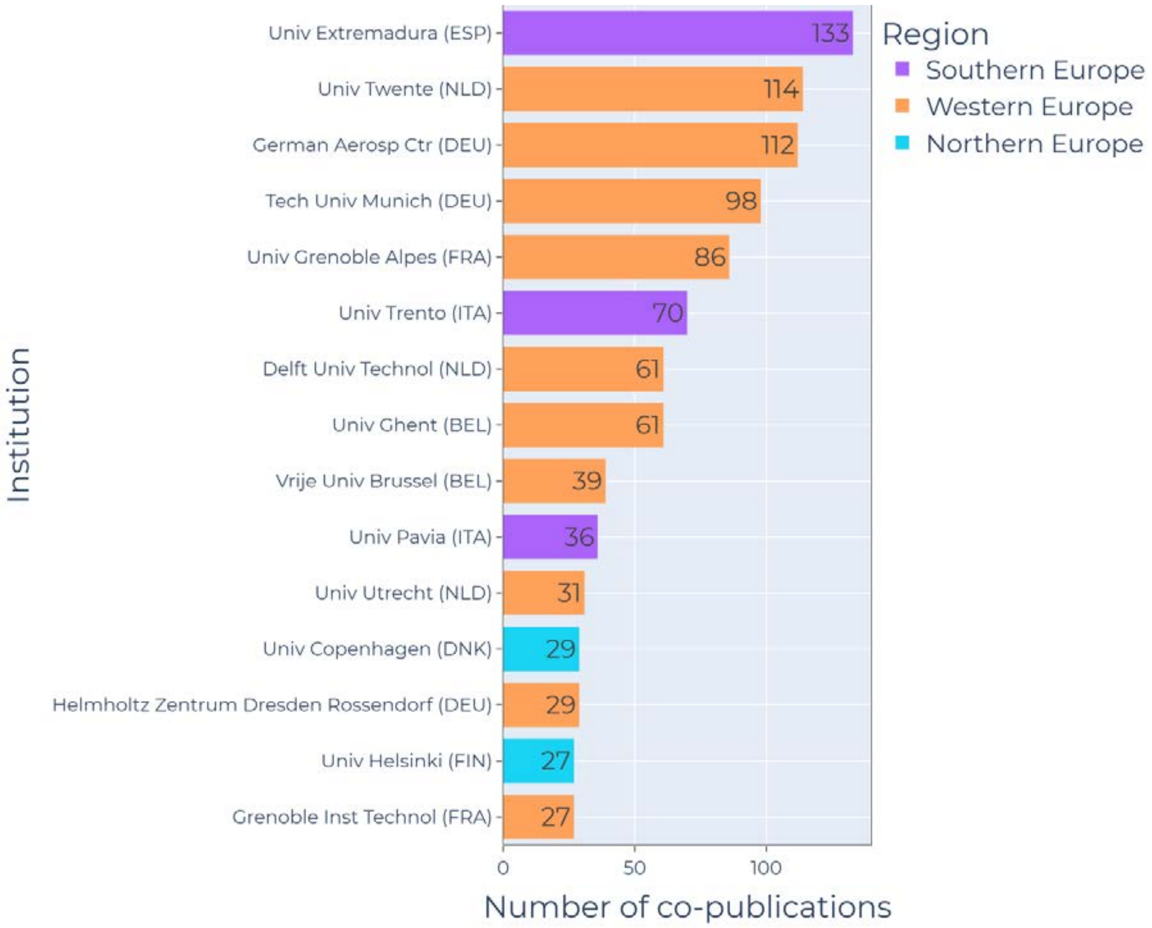


Figure 44. Top-15 most active collaborating institutes (limited to EU27 countries) publishing with Chinese authors within the subfield of Geological & Geomatics Engineering.

Some of the most prominent collaborations:

- University of Extremadura – Sun Yat-Sen University (57 co-publications)
- German Aerospace Center – Chinese Academy of Sciences (41 co-publications)
- University of Lancaster – Chinese Academy of Sciences (41 co-publications)

4.1.10.4 Industrial Engineering & Automation

In Industrial Engineering & Automation we found 2316 entries, which is ~5% of the total share. Despite the generally high contribution from the UK (figure not shown), the highest relative growth happened in Sweden (15-fold increase of co-publications between 2011 and 2022). Some other countries show a significant growth rate too, such as Denmark, Finland, France, Germany, Italy, and the Netherlands with ten times more co-publications over the indicated period (Figure 45).

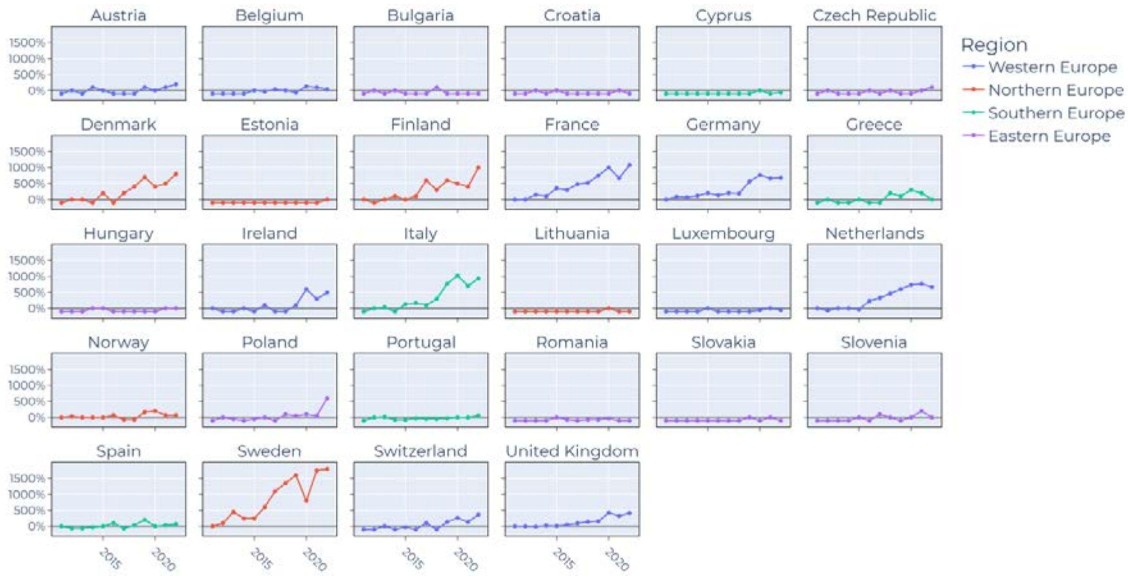


Figure 45. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Industrial Engineering & Automation.

On the institutional level, again these trends reverberate. The Royal Institute of Technology in Sweden leads the field not only for EU27 institutions alone (Figure 46), but also if all accession countries, and here in particular institutions from the UK, are considered (figure not shown). Apart from more generic collaboration patterns, some specifically close ties appear too. For instance, the University of Lisbon has mainly co-published with the University of Macau (33 from 37 co-publications in total), the University of Twente mainly with the Chinese Northeastern University (28/31) and the Technical University of Troyes mainly with Beihang University (20/22).

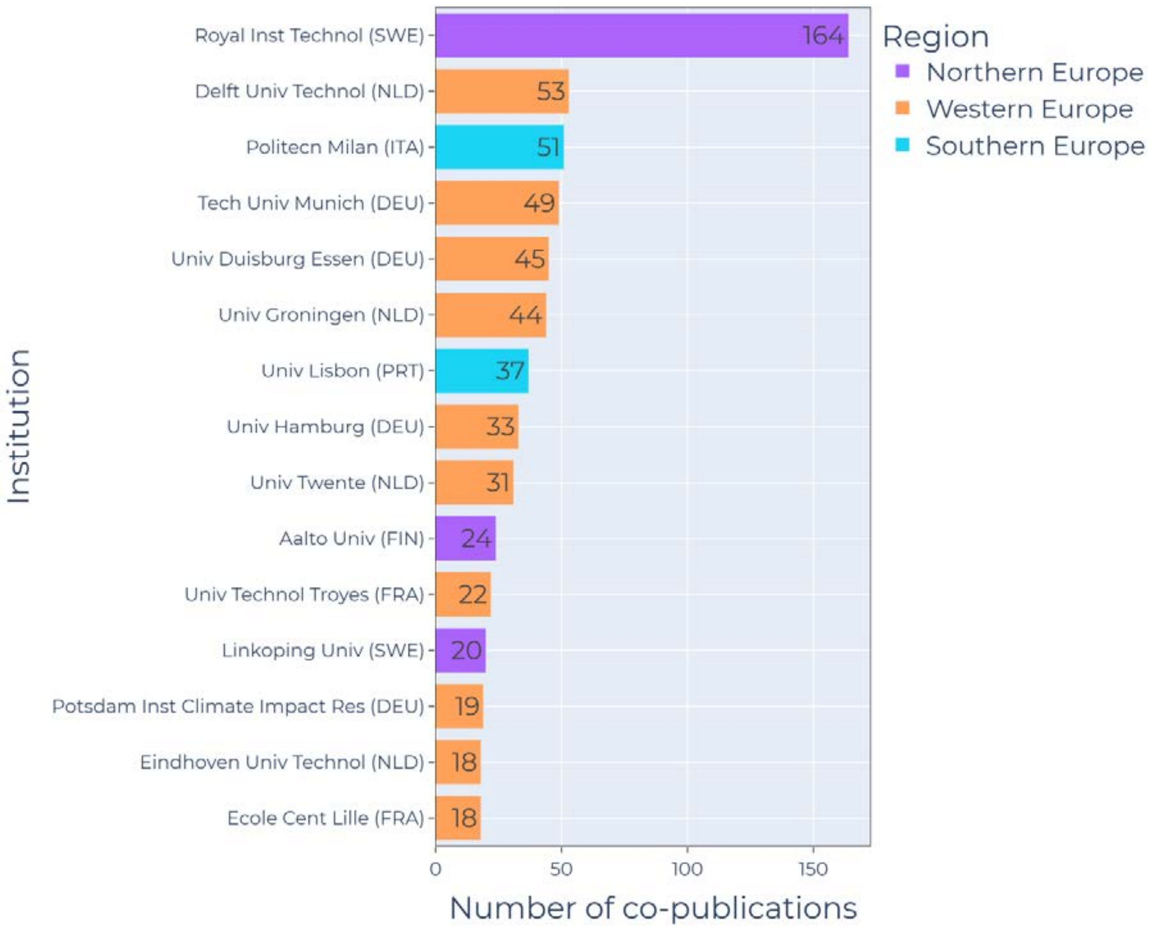


Figure 46. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of Industrial Engineering & Automation.

Some of the most prominent collaborations:

- University of Lisbon – University of Macau (33 co-publications)
- Royal Institute of Technology of Sweden – Chinese Academy of Sciences (23 co-publications)
- Imperial College of London – Shanghai Jiao Tong University (22 co-publications)

4.1.10.5 Electrical & Electronic Engineering

With 1387 co-publications in total, Electrical & Electronic Engineering can be still considered a substantial subfield. Apart from the strong presence of British institutions, also the Nordic countries Denmark, Norway and Sweden, Germany, the Netherlands, Italy, and Spain have experienced a ~20-fold increase in their co-publication output (Figure 47).

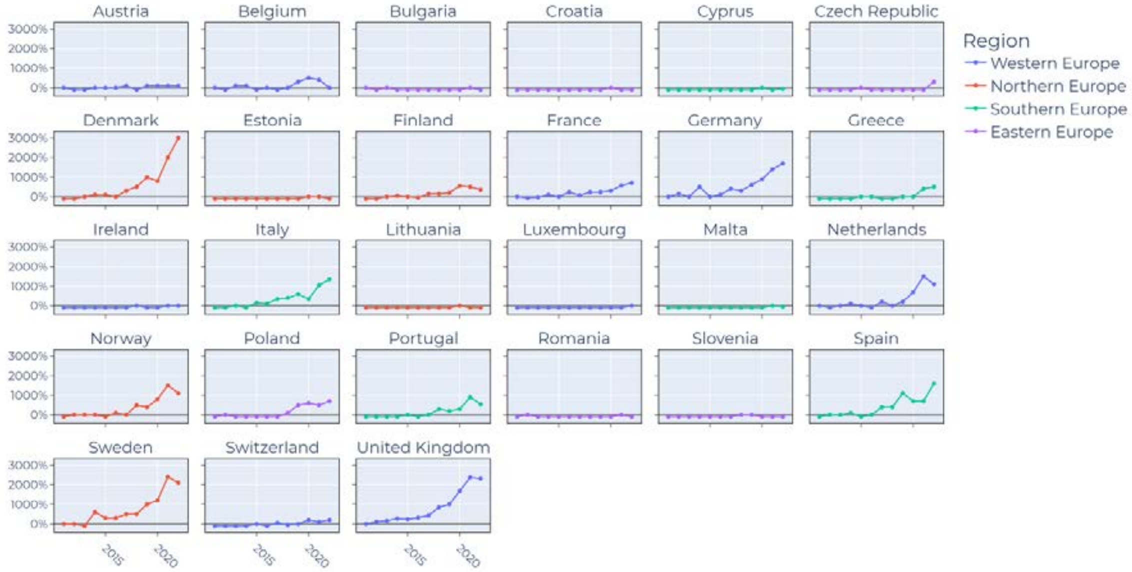


Figure 47. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Electrical & Electronic Engineering

Not surprisingly, similar results appear on the institutional level. With Aalborg University a Danish institution leads the field (68 co-publications) both with and without considering Norway, Switzerland and the UK (Figure 48).

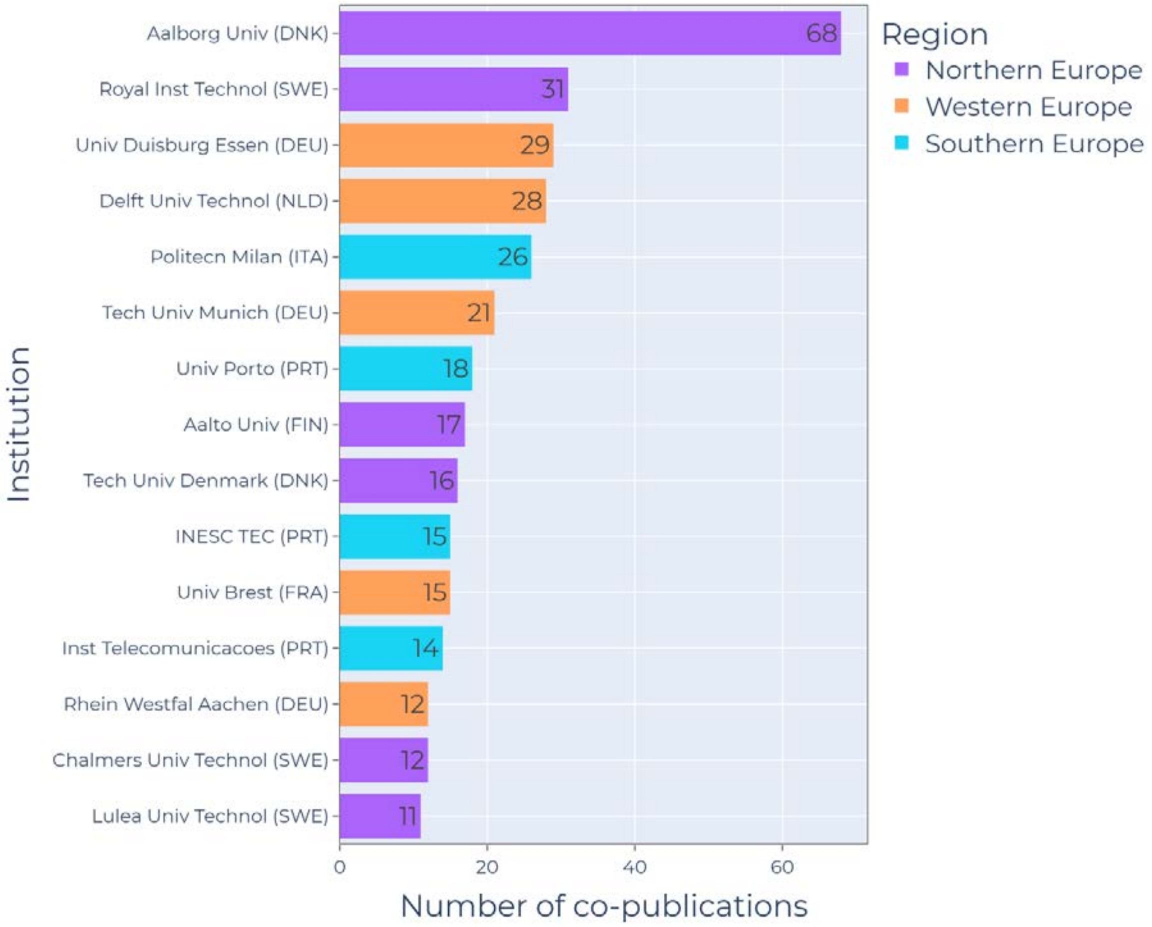


Figure 48. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of Electrical & Electronic Engineering.

Some of the most prominent collaborations:

- University of Porto – North China Electric Power University (16 co-publications)
- INESC TEC[1] – North China Electric Power University (15 co-publications)
- Aalborg University – University of Electronic Science and Technology (12 co-publications)

4.1.10.6 Energy

The subfield of Energy (part of Enabling & Strategic Technologies) is the last topic we have chosen given its high number of co-publications (1965; ~4% of the total sample). It is important to note that while the overall contribution from the UK is, as usual, high, it has decelerated significantly over our reporting period from 2011 to 2022 (from ~80% to ~40% in total contribution; Figure 49). At the same time Denmark's co-publications increased by 60 times, and also the growth rates in France, Germany and Sweden were considerably high (Figure 50).

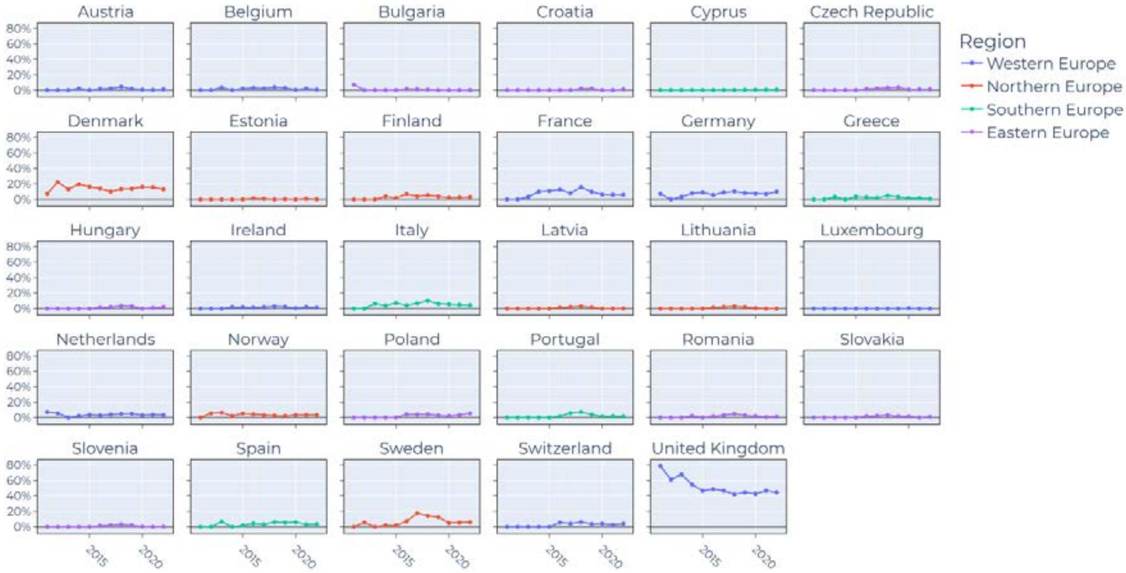


Figure 49. Yearly trends in country level contribution to co-publications of EU27/AC countries (in percent of entries related to country) in the subfield of Energy.

[1] Institute for Systems and Computer Engineering, Technology and Science (INESC TEC) is a research & development institute located on the campus of the Faculty of Engineering of the University of Porto

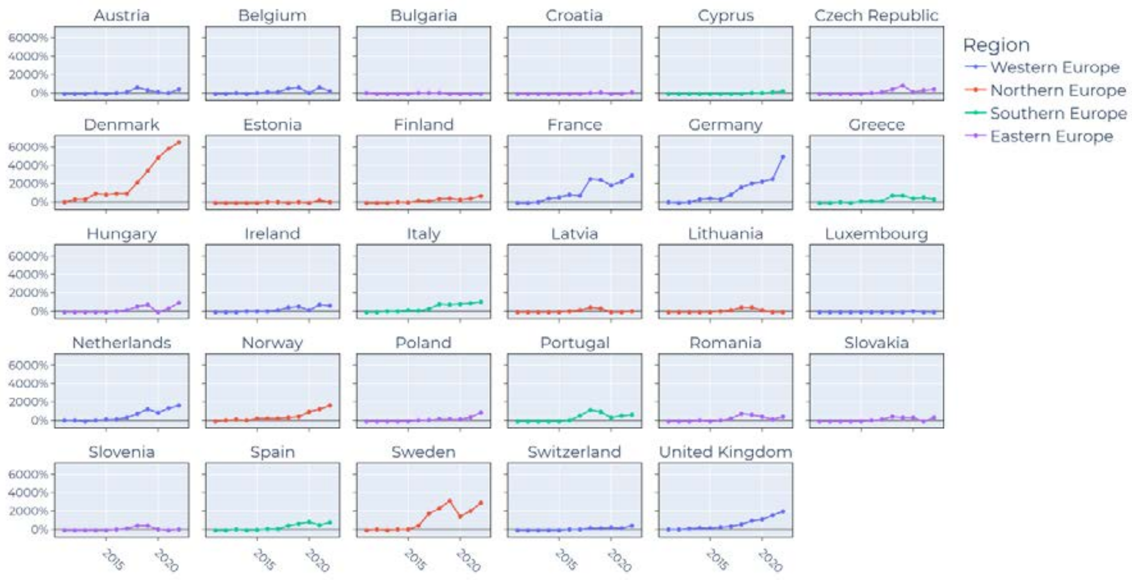


Figure 50. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Energy.

On the level of EU27 institutions alone, Aalborg University (156 records) and the Technical University of Denmark (120) lead the field and are by far the largest contributors to EU27-China co-publications (Figure 51).

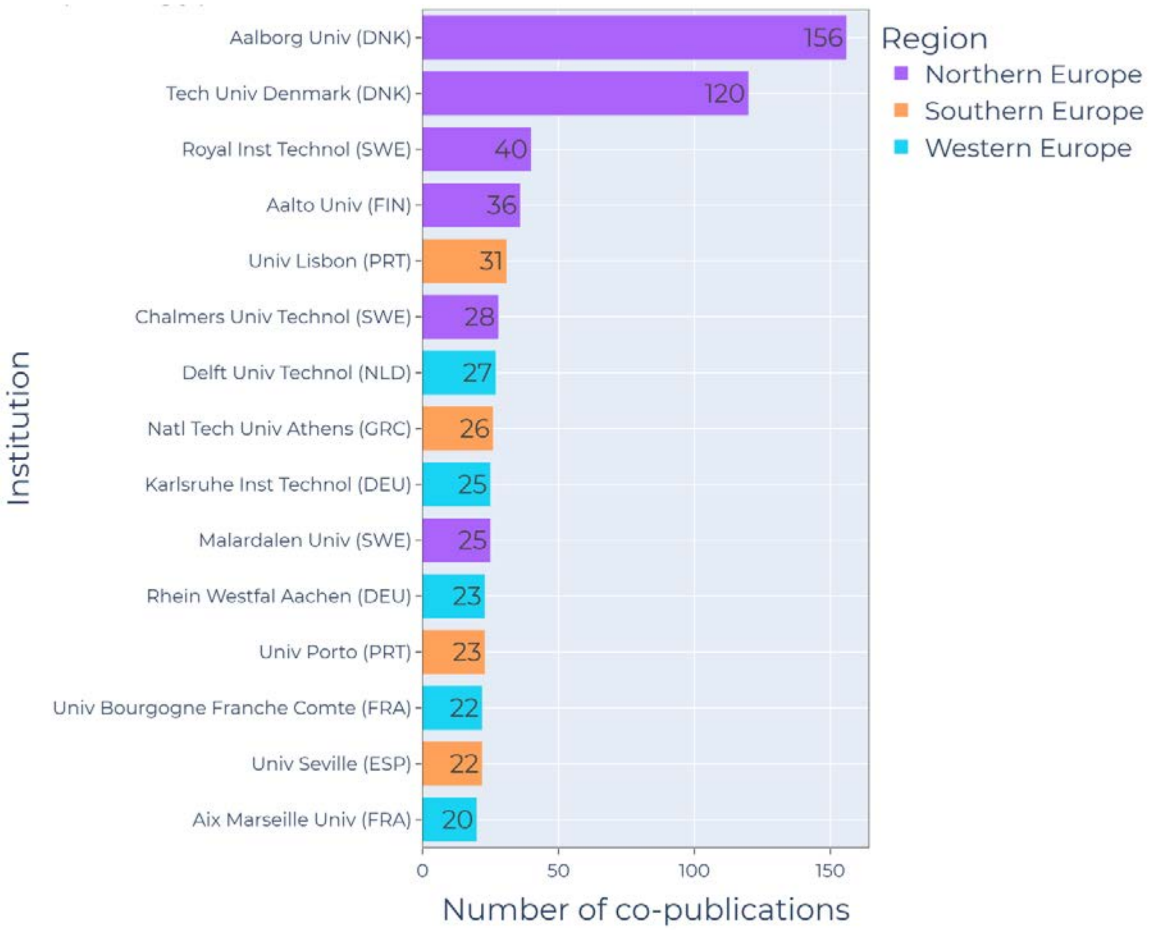


Figure 51. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of Energy.

Some of the most prominent collaborations:

- Robert Gordon University, Scotland – Southwest University of Science and Technology (50 co-publications)
- Aalborg University – University of Electronic Science and Technology (48 co-publications)

In addition to the aforementioned partnerships, there's another remarkable pattern worth highlighting. Within this subfield, several institutions, both from China and Europe, seem to frequently collaborate or at least share similar co-publication patterns. These collaborations range roughly from 17 to 10 co-publications each. The breakdown of participators is the following:

- China
    - The Chinese Academy of Science
    - University of Electronic Science and Technology
- Europe
    - Technical University of Denmark
    - University of Lisbon
    - Karlsruhe Institute of Technology
    - Aalto University
    - National Technical University of Athens
    - Chalmers University of Technology
    - University of Seville
    - Aix Marseille University
    - Imperial College of London
    - University of Warwick
    - University of Strathclyde

4.1.10.7 Analytical Chemistry

We include Analytical Chemistry for a further analysis as it accounts for the vast majority (73%) of co-publications in Chemistry. Additionally, the annual number of co-publications has increased significantly compared to other subfields (~15-fold; Figure 52).

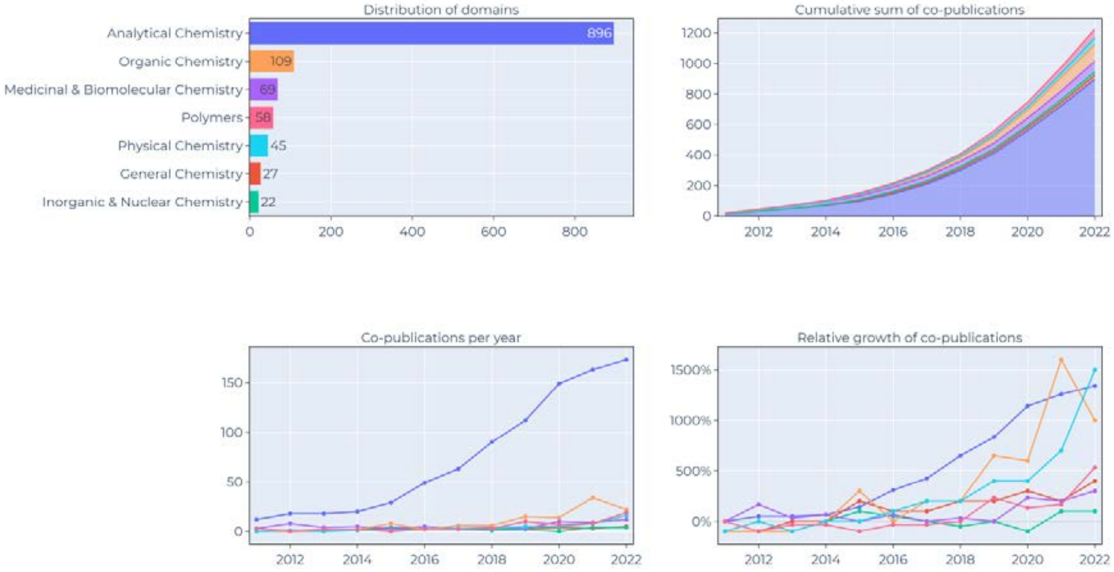


Figure 52. Detailed distribution of subfields and respective tendencies of co-publications classified in the field of Chemistry, and the dominance of Analytical Chemistry. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

The relative increase in co-publication output by country shows that Poland, despite having no institutions with co-publications in Analytical Chemistry, experienced a sudden general increase in 2018. This is consistent with the overall raise of Poland's co-publication activity with China. Other than that, the UK (~15-fold) and Spain (~10-fold) consistently increased their co-publication numbers, while starting with no or only few co-publications in the early 2010s (like the majority of European countries) (Figure 53).

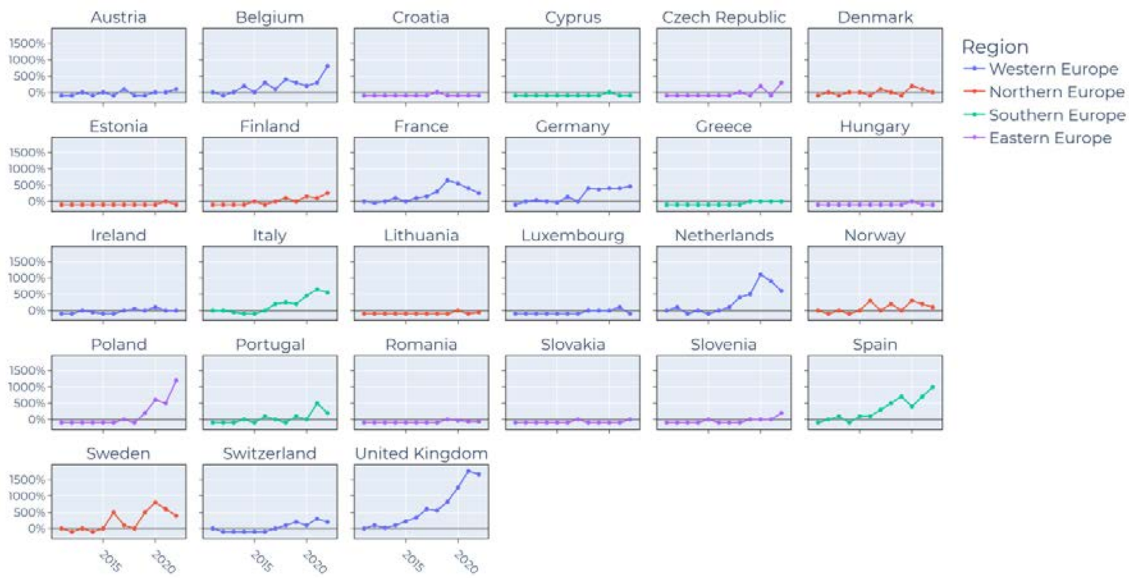


Figure 53. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Analytical Chemistry.

Focusing on the most involved institutions, we found no specifically emerging collaboration networks between EU27/AC and Chinese institutions worth mentioning. Within the EU27, the top three contributors were the Technical University of Delft (19 entries), the Technical University of Munich (14 entries) and the Catholic University of Leuven (12 entries). In addition, the Opole University of Technology in Poland is a significant contributor, playing its part in the previously mentioned increase of Polish co-publications in Analytical Chemistry (Figure 54).

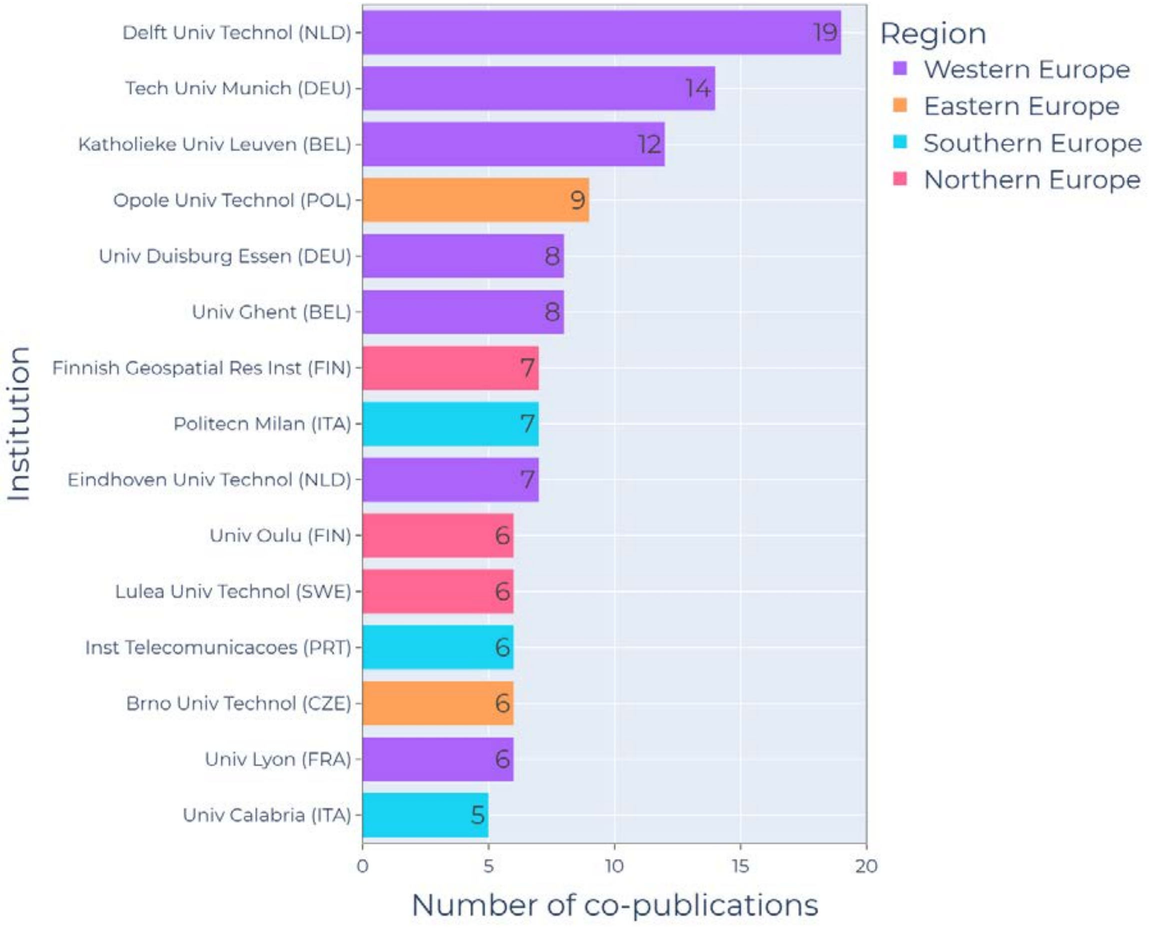


Figure 54. Top-15 most active collaborating institutions (limited to EU27 countries) publishing with Chinese authors within the subfield of Analytical Chemistry.

Some of the most prominent collaborations:

- Newcastle University – University of Electric Science and Technology (9 co-publications)
- Technical University of Munich – Tongji University (7 co-publications)
- University of Glasgow – University of Electric Science and Technology (5 co-publications)
- University of Cambridge – Beihang University (5 co-publications)

4.1.10.8 Distributed Computing

Distributed Computing (a subfield within Information & Communication Technologies) was selected because of its significant growth in scientific output. The vast majority of the total 560 co-publications were published after 2017, resulting in an 80-100-fold annual increase from 2018-2022 compared to the baseline numbers in 2011 (Figure 55).

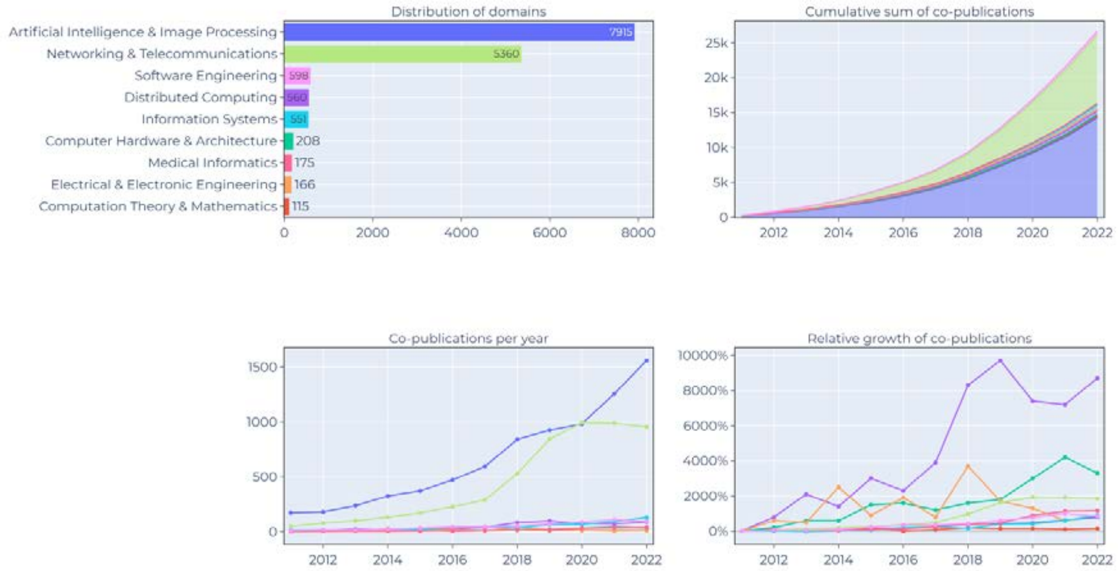


Figure 55. Detailed distribution of subfields and respective tendencies of co-publications classified in the field of Information & Communication Technologies, and the momentum of Distributed Computing subfield. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

Figure 56 shows that earlier than 2017, it was mostly the UK which contributed to co-publications in Distributed Computing. Other more or less significant contributors like Germany, Norway, Italy and Sweden started to raise their share with or after 2017.

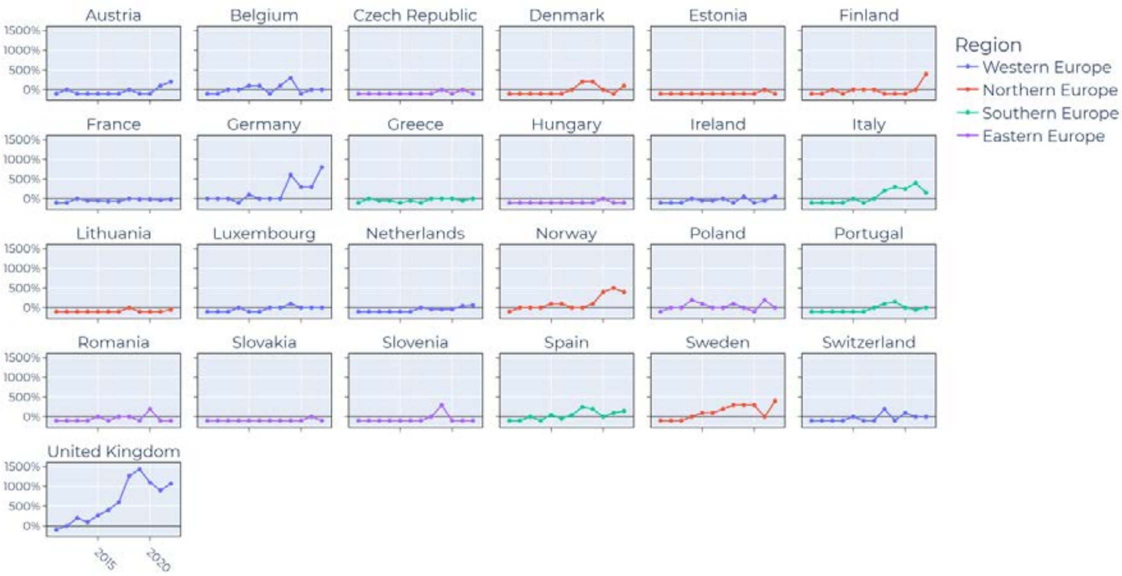


Figure 56. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Distributed Computing.

Because of this specific role of the UK, we decided for the next figure including the associated countries (Figure 57). As can be seen below, the five most active institutions are from the United Kingdom, which also dominates in terms of its overall presence of institutions. From the EU27, the Technical University of Valencia (16 entries), the University of Stavanger (14), the University of Naples Federico II (14), Luleå University of Technology and the University of Amsterdam (9) made it into the top-15.

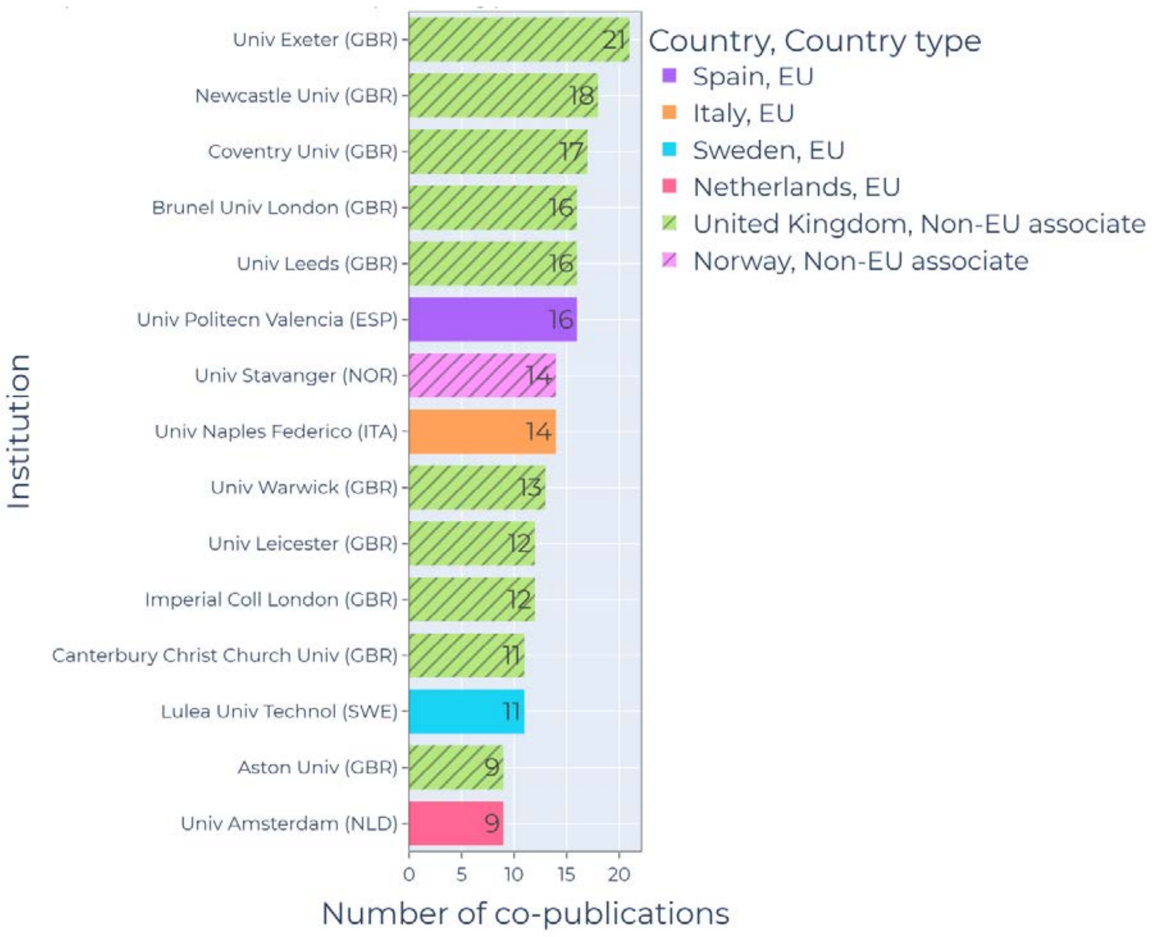


Figure 57. Top-15 most active collaborating institutions (including all EU27/AC countries) publishing with Chinese authors within the subfield of Distributed Computing.

Some of the most prominent collaborations:

- Brunel University of London –Tongji University (10 co-publications)
- University of Stavanger – Fuzhou University (10 co-publications)
- University of Ghent – Chinese Academy of Sciences (6 co-publications)

4.1.10.9 Nanoscience & Nanotechnology

An unprecedented relative growth for co-publications was observed in Nanoscience & Nanotechnology (Figure 58). Especially after 2018 this research subfield (part of Enabling & Strategic Technologies) showed huge increases, proven by a 120-fold acceleration in scientific outputs between 2022 and the 2011 baseline.

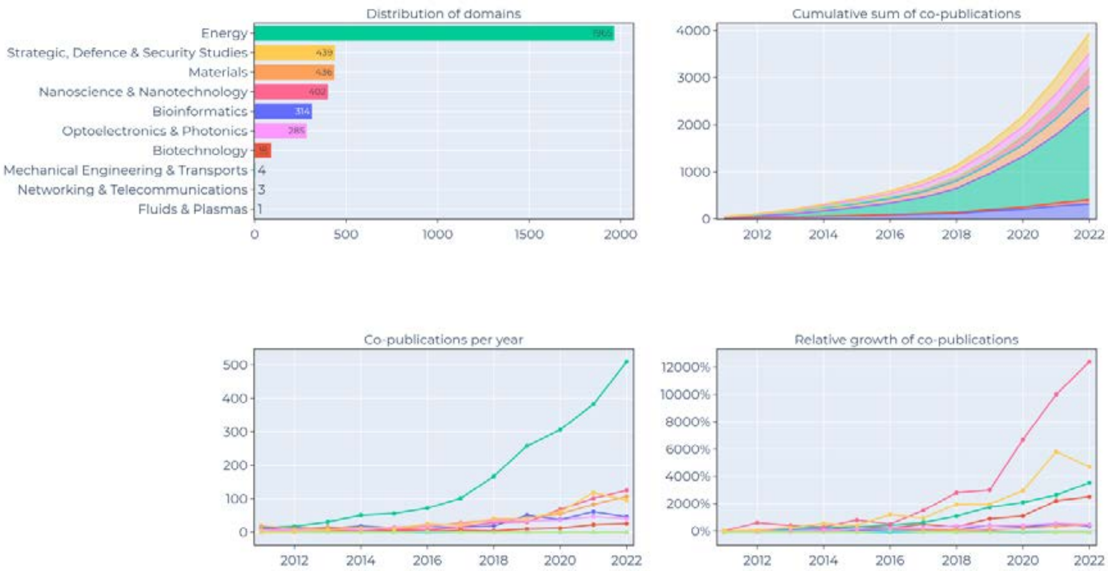


Figure 58. Detailed distribution of subfields and respective tendencies of co-publications classified in the field of Enabling & Strategic Technologies, and the growth of Nanoscience & Nanotechnology subfield in recent years. From left to right, top to bottom: overall distribution of fields; cumulative sum of co-publications; annual scholarly output and relative growth in annual scholarly output of co-publications, indexed to 2011.

At the country level, Germany and the United Kingdom were the two countries with significant increases in co-publication output, whereas some other European countries had no co-publications at all (Figure 59). This is similar to the earlier analysis of Distributed Computing, and probably has to do with the relative novelty of these two research topics. Figure 60 then lists the most active institutions in Nanoscience & Nanotechnology including both EU27 and AC.

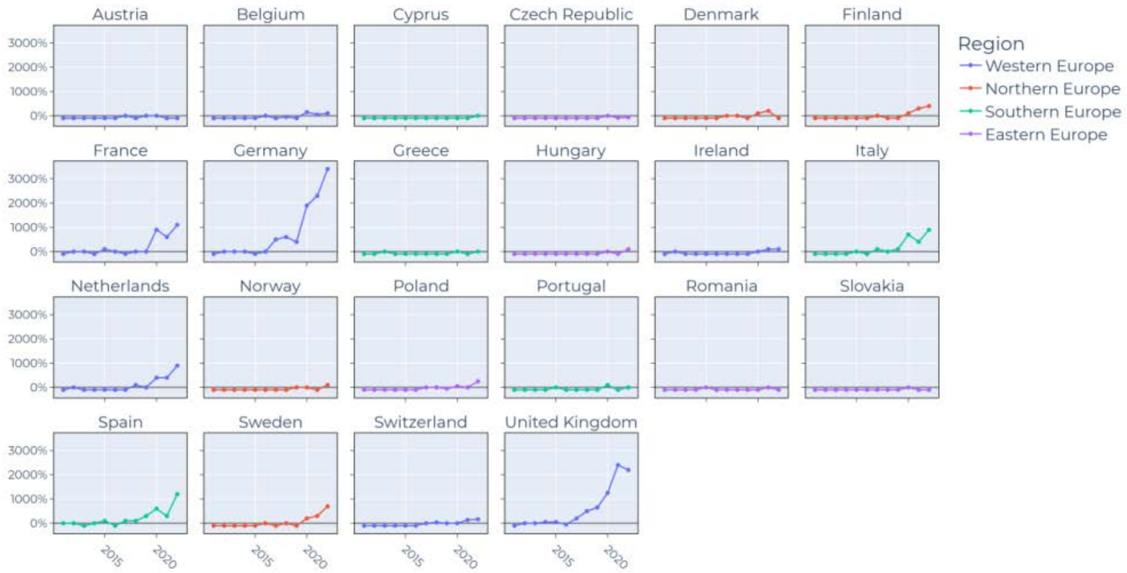


Figure 59. Relative growth at country level of annual scholarly output (indexed to 2011) of co-publications in the subfield of Nanoscience and Nanotechnology.

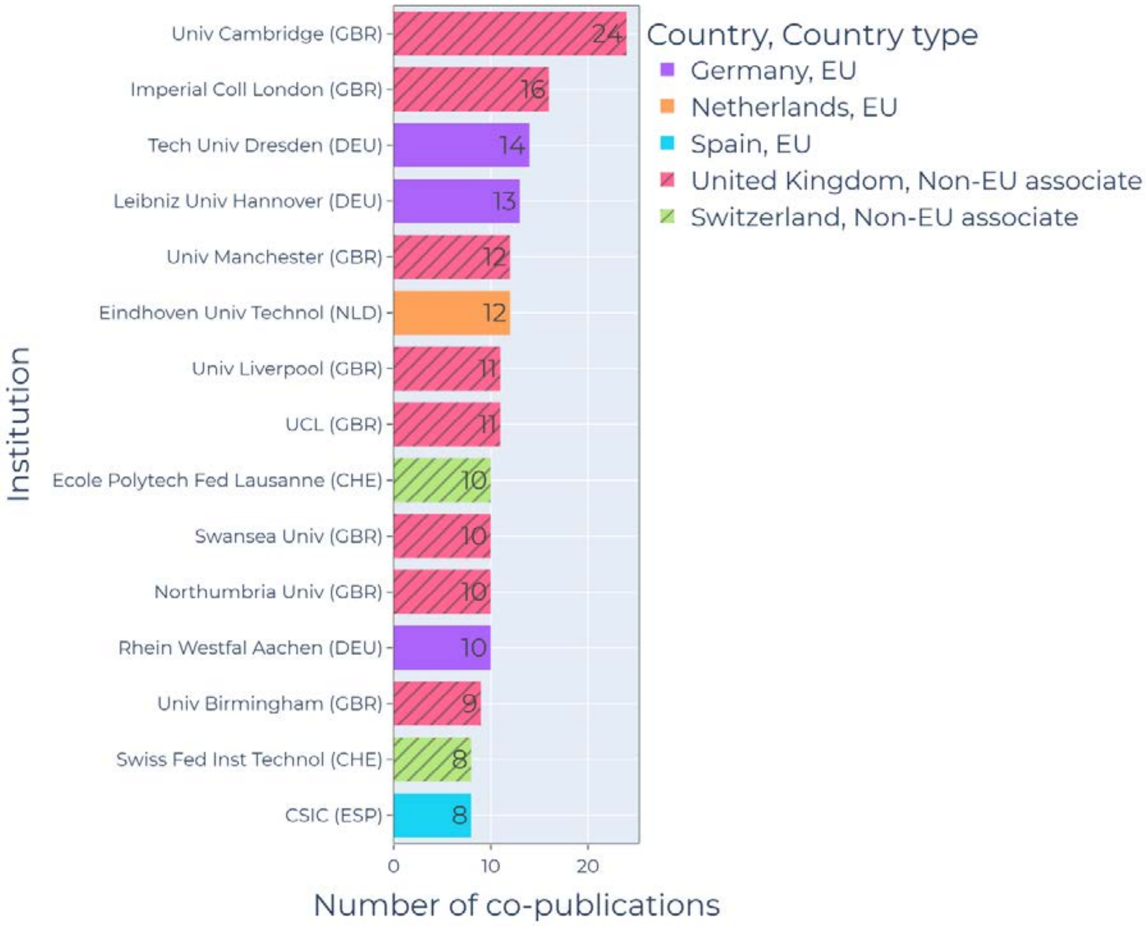


Figure 60. Top-15 most active collaborating institutions (including all to EU27/AC countries) publishing with Chinese authors within the subfield of Nanoscience and Nanotechnology.

Some of the most prominent collaborations:

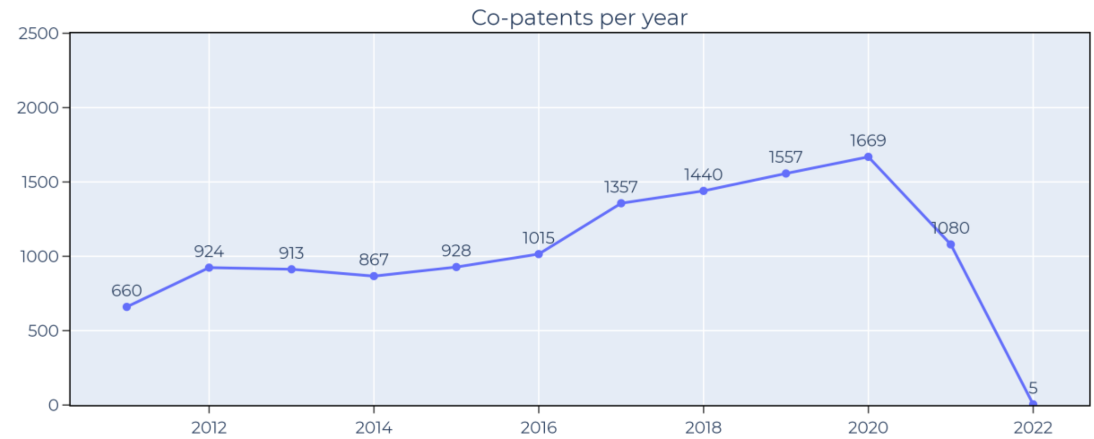
- Leibniz University of Hannover –Tongji University (13 co-publications)
- University of Basque Country – Southeast University (6 co-publications)
- University of Cambridge – Zhejiang University (6 co-publications)
- Swansea University – University of Electronic Science and Technology (6 co-publications)

4.2 Co-patent analysis

4.2.1 Overall trends and disclaimers

In our co-patent analysis, we primarily focus on patents filed between 2011-2022 and which result from a joint effort of between legal entities from EU27/AC and China. Using these criteria, we found exactly 12415 patent applications (further also called "patent submissions"). Of these initial patent filings, 9780 are international 'W' applications, and 2635 are national 'A' patent applications.

As already mentioned in our chapter on the methodology, there is a considerable bottleneck in patent analysis, which is the time lag. From the filing of a patent application to the publication of this application in the PATSTAT database, it takes about two years on average. This is why in this analysis, patent filing trends after 2018 must be considered indicative and most likely underestimate the actual rates. Patent numbers after 2018 are actually higher than this analysis tells, though we don’t know their exact dimension. Figure 61 shows the yearly trends in the number of co-patent applications. Taking the time lag into account, it shows a steady increase in co-patent applications between legal entities from the EU27/AC and China until 2020. After that, pending data on patent filing applications leads to a sharp decline of activity. Compared to the 2011 baseline, the increase in co-patent applications is steady, the number of submissions was ~1.5 times higher in 2022, thus one might expect further growth in later years. As a reminder to the reader, the noticeable declines post-2020 can be attributed to the inherent patent filing delays present in the PATSTAT database. It's essential to factor in this delay when interpreting recent data trends.



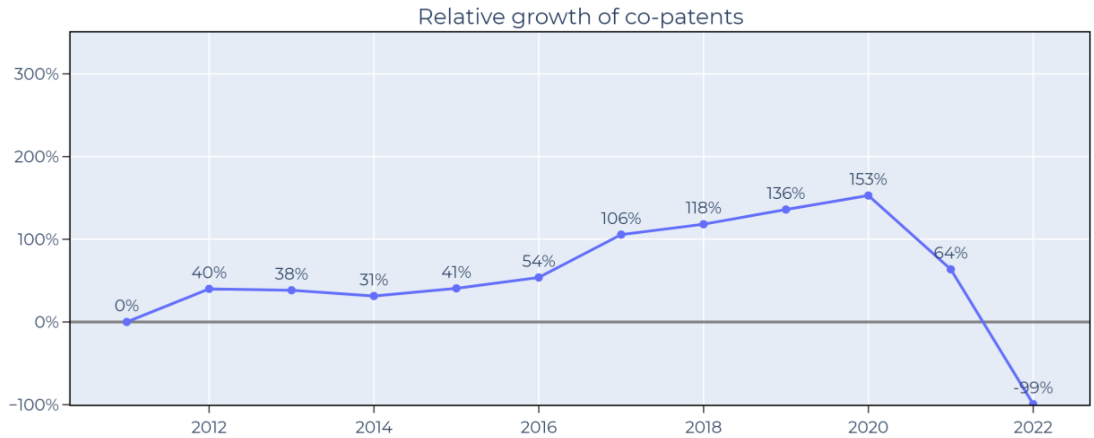


Figure 61. Overall trends in China-EU27/AC co-patent submissions; submitted co-patents per year and the relative growth in the annual submissions (indexed to 2011).

In the subsequent sections, we delve into the predominant patterns observed in the co-patent activities. Our analysis is anchored around the three principal entity types associated with patent filings:

- application authority: The official body or organization where the patent application is submitted and processed.
- applicant(s): The individual, organization, or entity (can be multiple per application) that files the patent application, asserting rights to the invention.
- inventor(s): The individual or group of individuals who conceived the original idea or innovation and is responsible for the creation detailed in the patent.

This structured approach offers a comprehensive view of the intricate dynamics at play in the co-patenting landscape.

4.2.2 Co-patents by application authority

The patent authority in the PATSTAT database refers to the national or regional patent office that has processed a particular patent application or patent. We now turn to the distribution of these co-patents by application authority (Figure 62). While there appears to be almost no co-patents lodged with Chinese patent authorities, the situation is not as straightforward as it seems. There are considerable biases in the quality of records based on the application authority providing the data. We have found that in some patent authorities the initial filings of PCT patents frequently omit the country of the applicant or inventor (Figure 63). **The Chinese patent authority is one of the most prominent examples of this negligence**. For our analytical scope, such omissions prevent the classification of concerned patents as valid EU27/AC-China co-patents and as such mean an additional bias to be taken into account.

The exact reason for this data quality issue varies by authority. Different patent authorities have their own rules, procedures, and criteria for processing patents. However, this concern has already been noted before in the case of China. In the early 2010s, the Chinese government introduced a series of regulations and incentives that drove up the number of applications but resulted in lower quality patent records (Prud'homme 2015). Albeit patent data quality was already low initially, accounting for the time lag the effect of this policy-shift can explain the further quality loss around 2015 at the Chinese application authority (Figure 63). In fact, from 2015 up to 2022, which marks the end of our study scope, the Chinese national patent office had no initial filings of PCT patents (as outlined in our initial data scope; refer to the Methods section) that provided valid nationality information for either applicants or inventors. In the following analyses the reader is advised to keep these potential biases in mind.

As shown on Figure 62 most patents applications were with WIPO (78.8%) and EPO (8.7%). This tendency has already been noted; China positions itself on the global innovation stage, inventors and corporations within its borders are increasingly directing their patent filings to influential markets, especially the U.S. and international institutions like the WIPO [8].

Among national patent offices, Germany (5.6%), The United Kingdom (3.3%) and France (2.1%) stand out as the most prominent application authorities used for co-patent applications. Figure 64 and Figure 65 also show the annual trends in patent filings. Here we note steady growths for

WIPO and EPO. Both German and French patents offices experience a steady filing inflow. The United Kingdom, however, shows a significant rise in applications from 2015 to 2017 (~5-fold growth) but then sees a decline in the subsequent years, and this decline appears to be earlier than the expected (~2020) general time lag of patent record processing of PATSTAT.

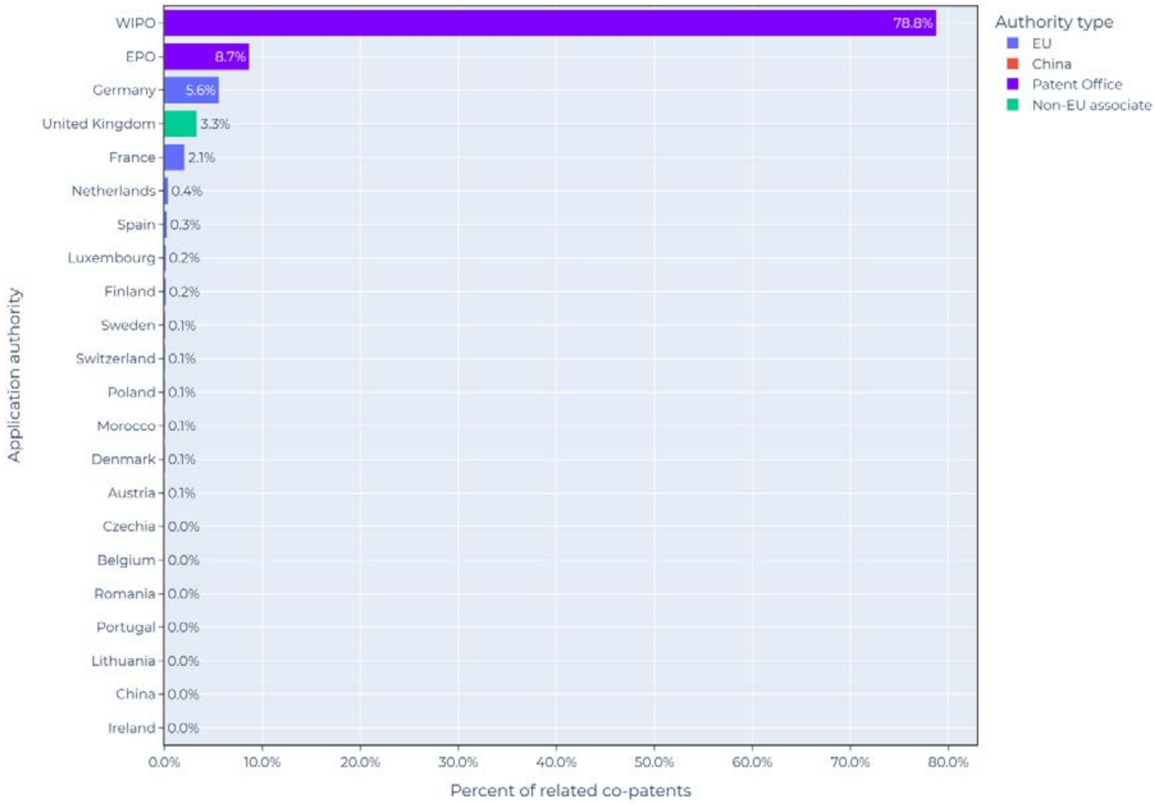


Figure 62. Distribution of co-patents by application authority.

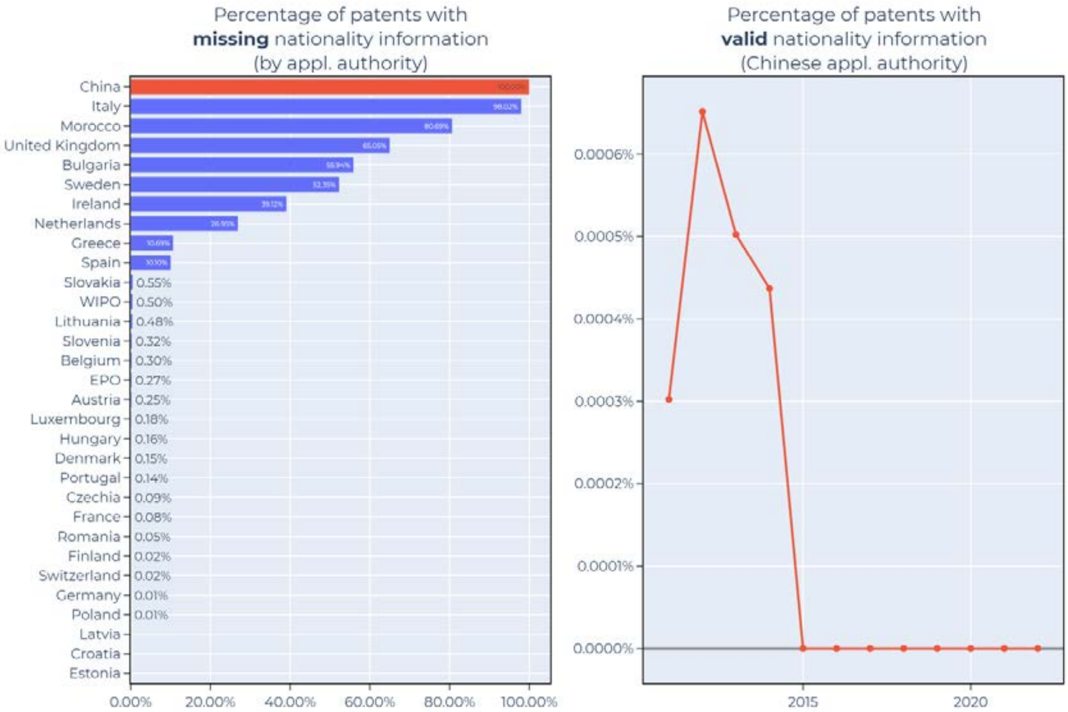


Figure 63. Data quality bias in patent submissions; left: percentages of patents containing mission information about the applicant's and/or inventor's country based on application authority; right: additional loss of data quality at the Chinese application authority, possibly due to the shift of policy in 2010.

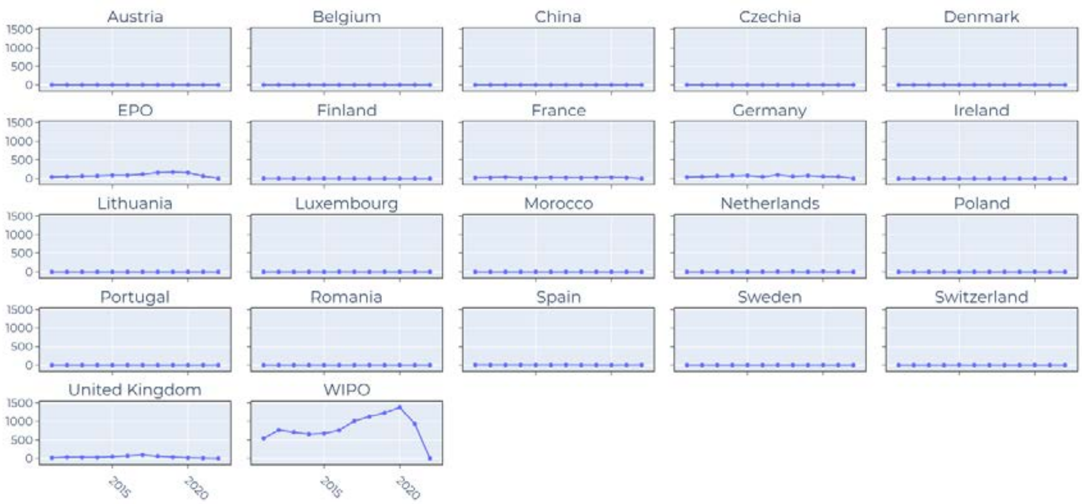


Figure 64. Trends in China-EU27/AC co-patents submissions by patent authority; submitted co-patents per year.

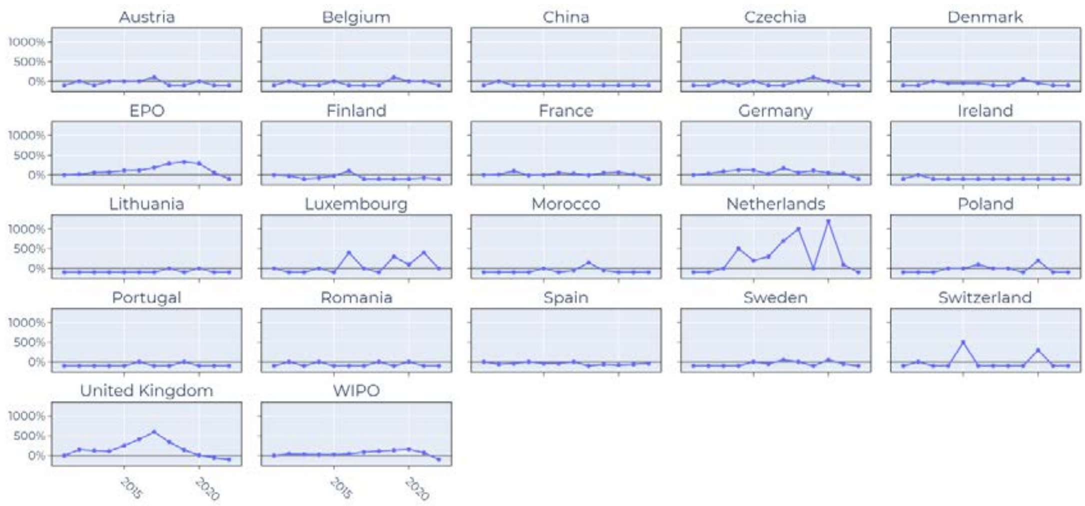


Figure 65. Trends in China-EU27/AC co-patents submissions by patent authority; submitted co-patents per year; relative growth in the annual submissions (indexed to 2011).

4.2.3 Co-patents by applicants and inventors

The PATSTAT database has two further types of entities tied to a patent application: applicant(s) and inventor(s). The applicant(s) of a patent are the person(s) or entity/entities that apply for a patent. They are essentially the "owners" or "holders" of the patent once it is granted. The applicant can be an individual, a group of individuals, a company, a research institution, or any other entity that has the right to apply for a patent. The inventor(s) are the actual person(s) who came up with the invention. They are the brains behind the idea or innovation. In other words, the inventor is the creator of the intellectual property. An inventor must be a natural person (i.e., an individual) and cannot be a company or organisation. The inventor may or may not be the applicant. For instance, if an employee invents something as part of their job, the employee is the inventor, but the company they work for might be the applicant and holds the patent rights.

Table 1 provides a comprehensive overview of patent ownership and inventorship classifications. It delineates instances where the co-patent filing's applicant/inventor hails from China, the EU27/AC region, or both, thus signifying cases of co-ownership or co-invention. Moreover, a subset of co-patents was identified wherein either the applicants or the inventors exclusively represented a third-party entity. We found out that co-patent applications are predominantly co-owned by both Chinese and European entities (8697 cases), whereas Chinese or EU27/AC owned co-patents are less frequent but still significant. The distribution of inventorship categories is more balanced. Interestingly, co-patents that had no European inventors are more likely to be co-owned (85%), than co-patents lacking Chinese inventors (74%).

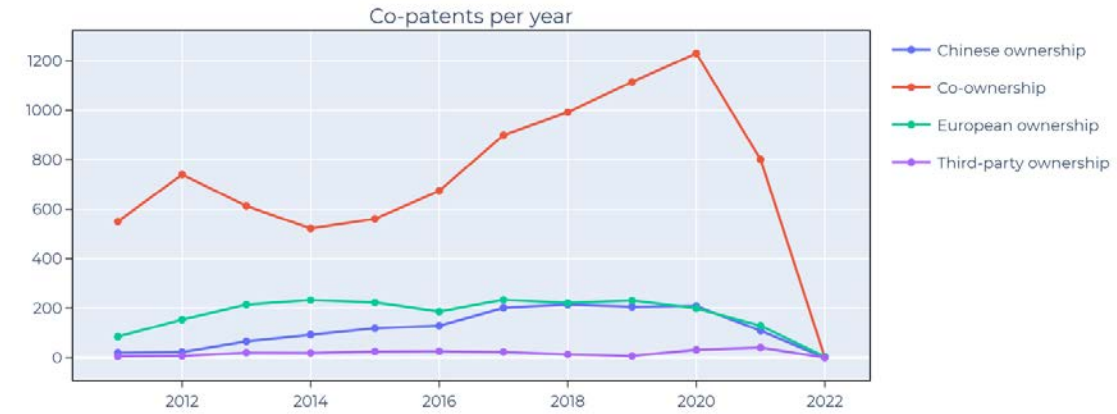
Table 1. Distribution of patent ownership and invention origin in Chinese-EU27/AC co-patents

applicant/inventor	Co-invention	Chinese invention	EU27/AC invention	Third-party invention	Total
Co-ownership	1998	3994	2631	74	8697
Chinese ownership	465	0	922	0	1387
EU27/AC ownership	1404	709	0	0	2113
Third-party ownership	218	0	0	0	218
Total	4085	4703	3553	74	12415

Figure 66 and Figure 67 present the annual trends in co-patent ownerships and inventorships. The principal observation of relevance here is the substantial relative surge in Chinese ownership, coupled with a concurrent upswing in European inventorships. **In a broader contextual framework, the data indicates that in the early stages of 2012, the trajectory of intellectual property flow leaned heavily towards Europe (marked by high numbers of Chinese inventorship, limited European inventorship, and modest Chinese ownership)**. However, this predisposition has waned over the past decade, as both inventorships and ownerships have reached a state of equilibrium between Europe and China. This finding is of particular relevance to prove the shift of dynamics in intellectual property distribution and flows between the two regions. This notable change of dynamics for intellectual property flows (measured by patent filing activity) is, at least partially, also addressed in these two reports from the OECD[1] and the European Parliament[2]. The rapid declines after 2020 are again due to the general patent filing delay in the PATSTAT database.

[1] https://www.oecd.org/china/50011051.pdf

[2] https://www.europarl.europa.eu/RegData/etudes/STUD/2020/603492/EXPO_STU(2020)603492_EN.pdf



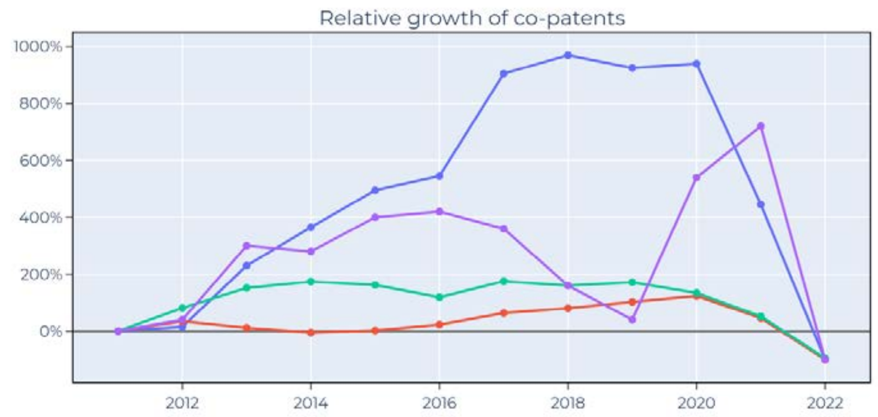
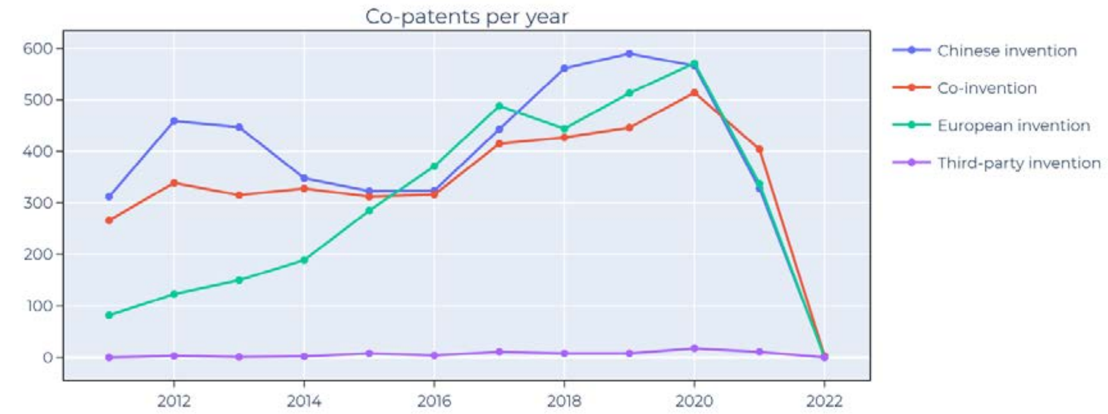


Figure 66. Annual trends of patent ownership categories of Chinese-EU27/AC co-patents. Number of filed patents and the relative growth of co-patents (indexed to 2011).



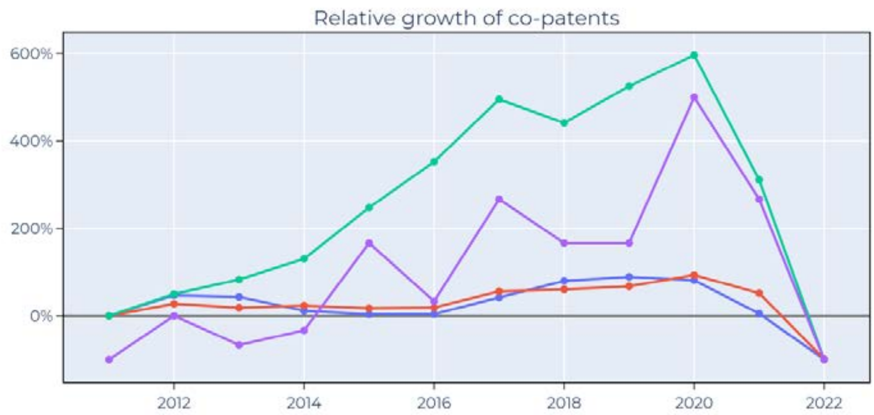


Figure 67. Annual trends of patent inventorship categories of Chinese-EU27/AC co-patents. Number of filed patents and the relative growth of co-patents (indexed to 2011).

In our subsequent analysis, we place a keen focus on the distribution of both applicants and inventors based on their nationalities. In simpler terms, we examine the proportion of patents that feature at least one inventor or applicant hailing from a specific country. Given the nature of our data, which revolves around co-patents shared between Chinese entities and multiple European counterparts, a notable observation emerges. Due to the singular representation of China contrasted against the collective representation of several European countries, we naturally anticipate a significant Chinese representation in the patents. To provide a ballpark estimate, we expect that approximately half (~50%) of the contributions in these co-patents will be attributed to Chinese entities.

Figure 68 shows the distribution of co-patents by the country of the applicant. Slightly more than half of the co-patents (57.5%) contain at least one Chinese applicant (meaning other co-patents included Chinese participants in the role of inventors). Germany (20.4%) Finland (15.4%), Sweden

(10.8%), France (9.8%) and Switzerland (6.4%) are also popular origins of applicants. This is in contrast to Eastern European and Baltic countries with only very few applicants for co-patents.

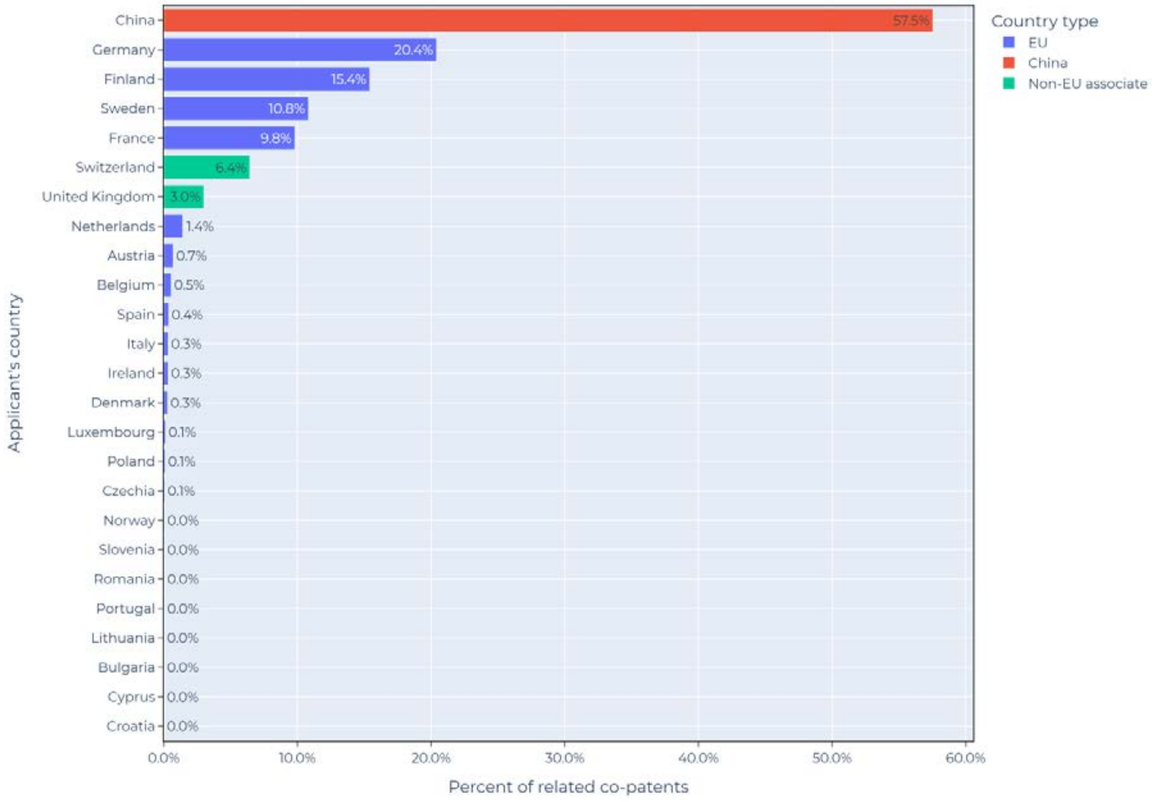


Figure 68. Distribution of co-patents by applicant country; percent of co-patents having at least one applicant from the respective countries.

The figure on distribution of inventors by country (Figure 69) shows a few significant differences to applicants. China's representation is more dominant (71.2%), a fact that concurs with the initial intellectual property bias shown in Figure 67. Among EU27/AC countries, Germany (28.6%) and Sweden (12.7%) are leading.

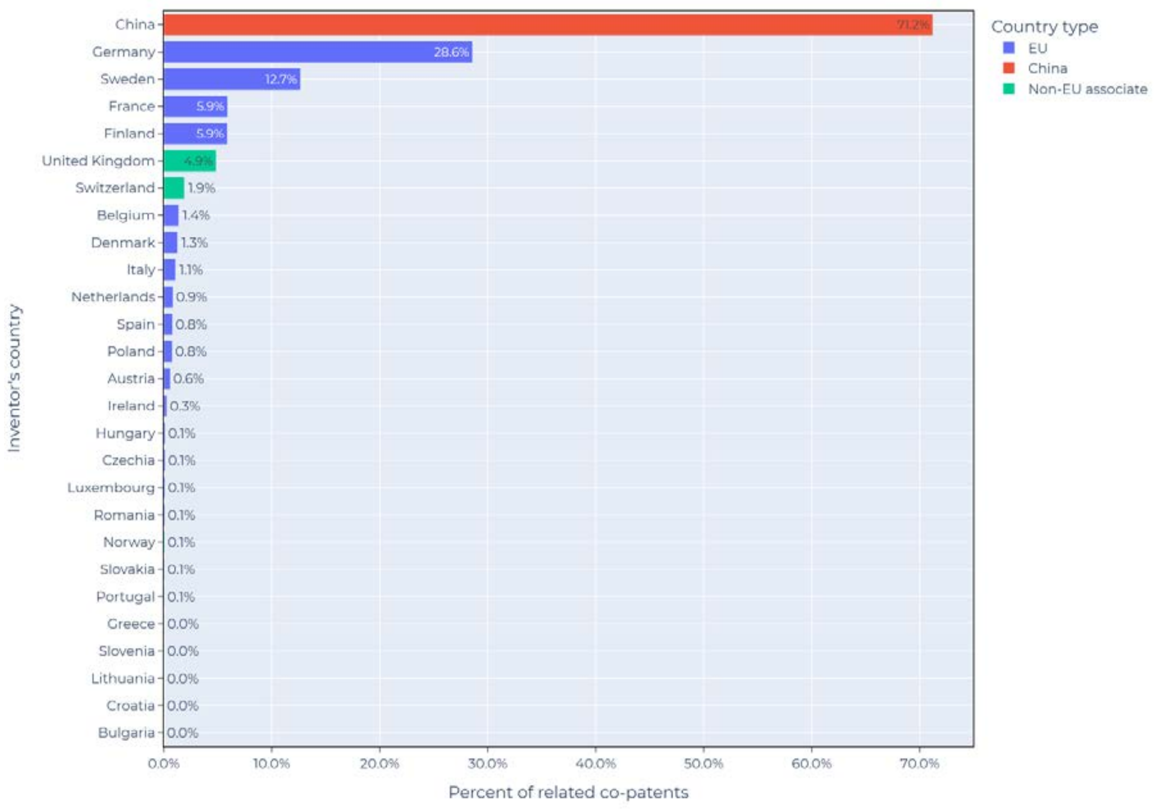


Figure 69. Distribution of co-patents by inventor country; percent of co-patents having at least one inventor from the respective countries.

Our analysis extends to discerning patterns linked to applicant roles. Figure 70 and Figure 71 spotlight the 15 most active co-patent applicants from the EU27/AC and China, respectively.

For EU27/AC (Figure 70), we note the involvement of many renowned large corporations (or their affiliated entities), such as Nokia, Ericsson, Siemens, Bosch, and BMW. This finding proves that co-patenting between EU27/AC and China is primarily a commercial endeavour, dominated by the telecommunications/electronics sector and industrial heavyweights from Germany and France. An exception is CNRS (*Centre national de la recherche scientifique* - French National Centre for Scientific Research). CNRS is a state-backed non-profit research entity and has a rich history of participation in global research initiatives. 67 joint patent applications with Chinese entities were found for CNRS over the period 2011-2022.

For China, a more diverse picture emerges (Figure 71). Several of the most active applicants are Chinese offshoots of the aforementioned European firms (e.g., Nokia, Siemens). A subsidiary of the US-based NAVTEQ (NAVTEQ SHANGHAI TRADING CO LTD) also appears as a strong player. Yet, there's also a clear representation of genuine Chinese corporations, such as Huawei, Lenovo, TCL, and Geely. It's worth highlighting that all top-15 applicants from China are large corporations.

Summarising the portfolio of China's leading applicants, again it is the telecommunications/electronic sector, which is most represented, alike to the situation in the EU27/AC. Apart from that, the data hints to ongoing patent collaborations in the automation and vehicle production (with e.g. ABB, Bosch, BMW, and Geely) and the chemistry and consumer goods sectors (e.g. L'Oreal, Rhodia, and Henkel).

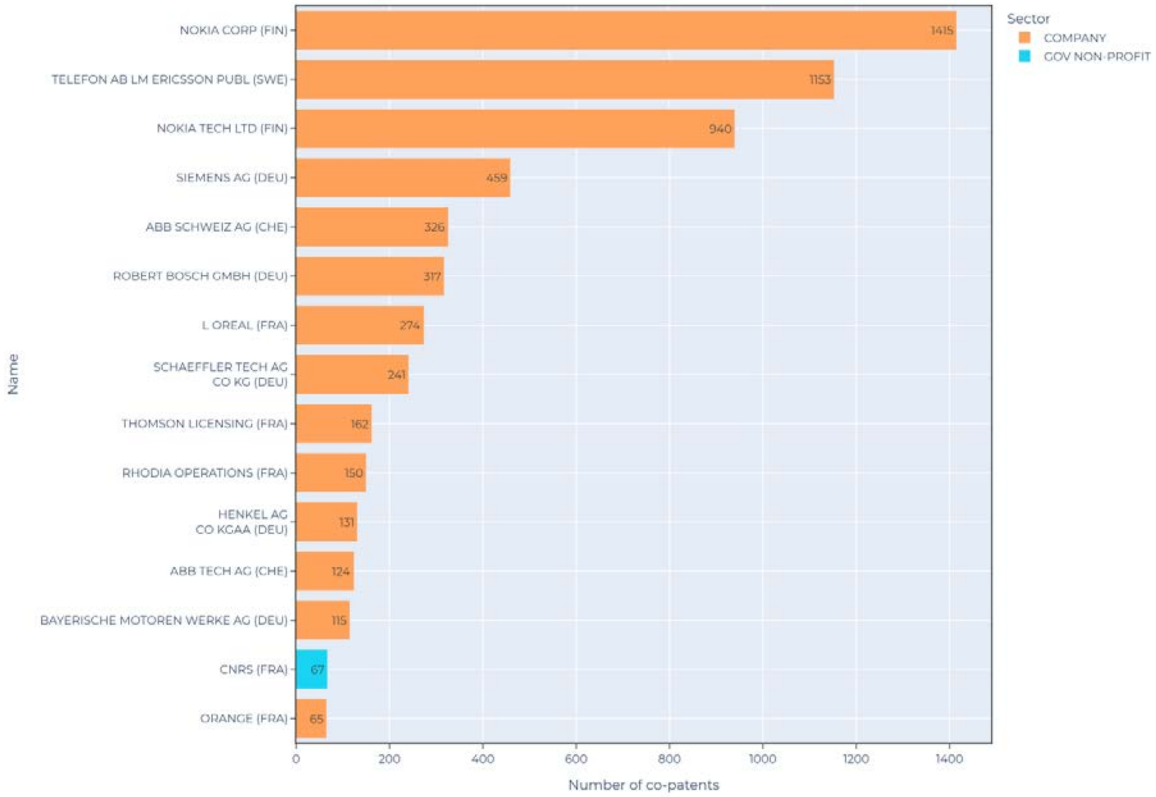


Figure 70. Top-15 most active EU27/AC applicants submitting co-patents with Chinese participants (either applicant or inventor)

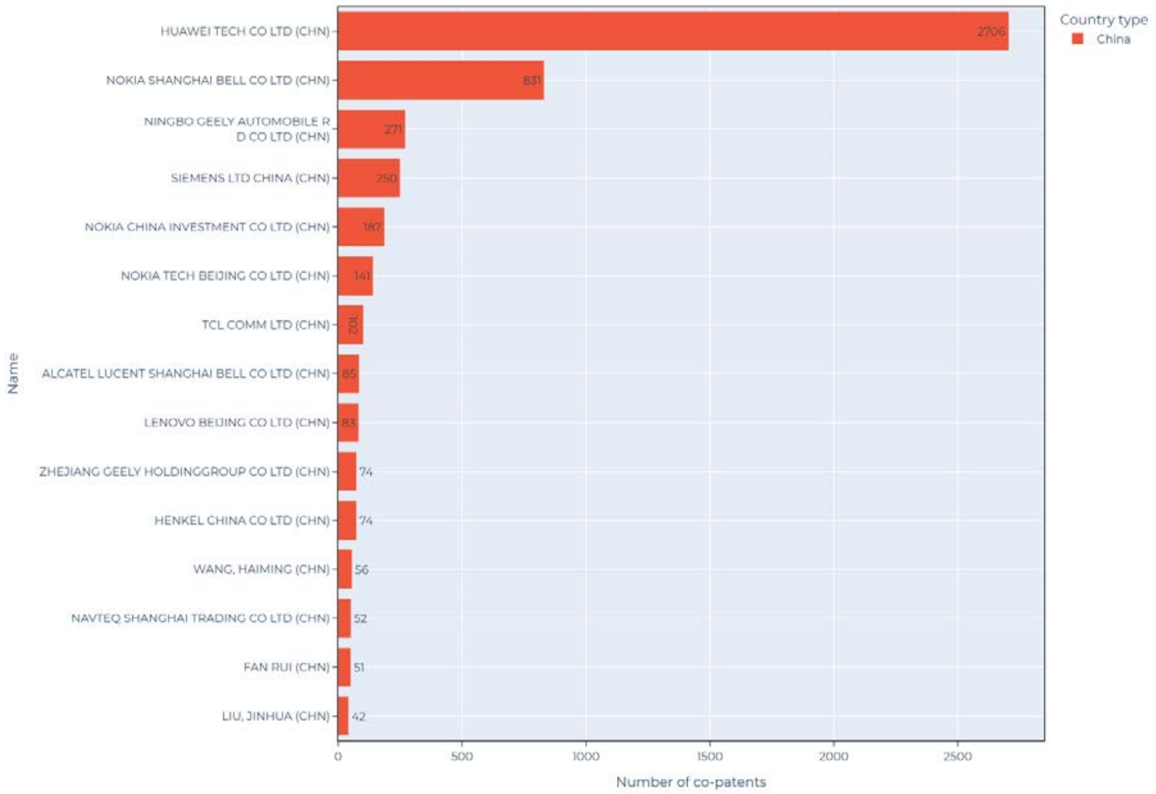


Figure 71. Top-15 most active Chinese applicants submitting co-patents with EU27/AC participants (the European participants are either applicants or inventors)

Figure 72 delineates the collaborative patent ownership dynamics among the top-20 co-applicants. This reflects instances where both China and a EU27/AC country contributed at least one applicant in a joint patent filing. It's important to recognise that in certain scenarios these co-applicants are essentially European-based subsidiaries, such as the ones from Henkel, Rhodia, Nokia, and Siemens. Other than the industry sectors already highlighted, companies in the top-15 come from sectors such as medical diagnostics and microscopy (Fresenius Medical Care and Leica) and automotive supply (Schaeffler Tech; Figure 70). Moreover, we observe some specific academia with industry networks: The Dalian Institute of Chemical Physics (affiliated with the Chinese Academy of Sciences) boasts ten co-patent applications in collaboration with Robert Bosch GmbH and one with Rhodia Operations respectively. Concurrently, Tsinghua University and Robert Bosch GmbH have co-filed 17 co-patents and while CNRS and a Rhodia subsidiary in China co-filed three.

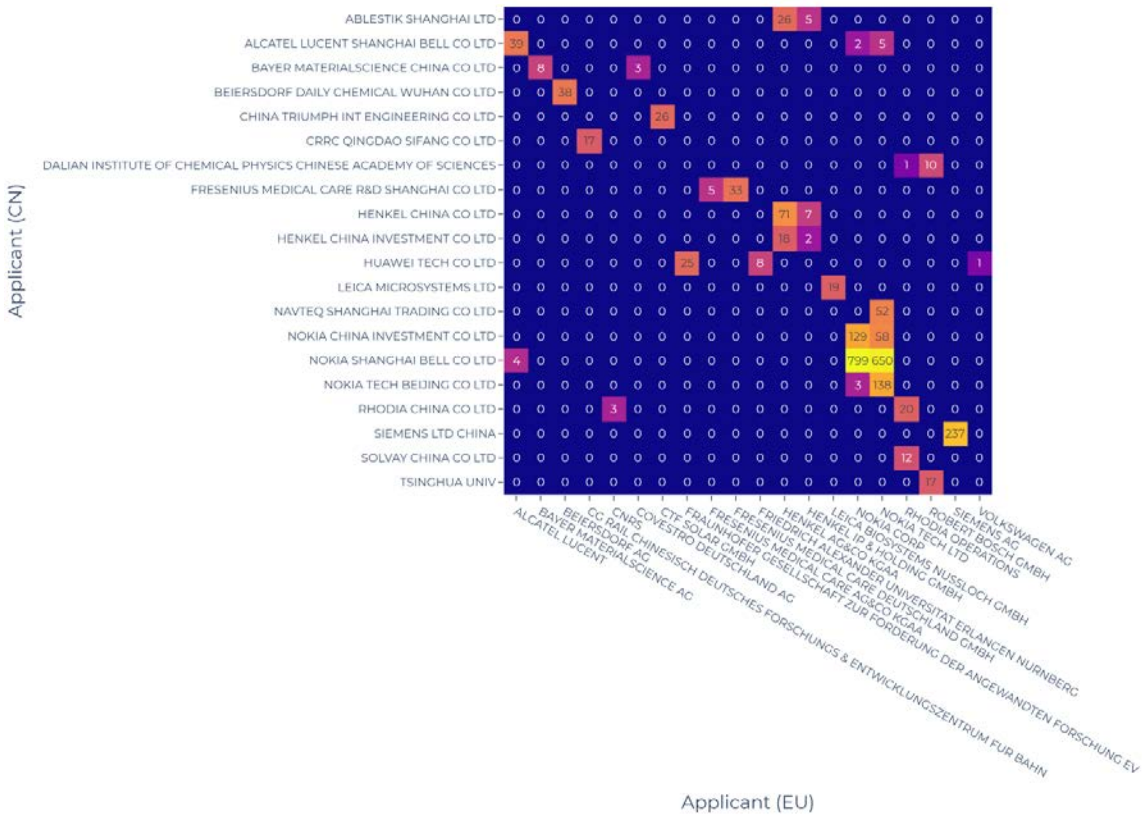


Figure 72. Co-application patterns between the top-20 most active co-applicants in China and EU27/AC countries.

Next we shift our focus on understanding the inclination of Chinese applicants towards European countries, emphasising the innovative contributions of inventors from EU27/AC countries to Chinese patenting entities. Figure 73 illustrates these contributions by depicting who has collaborated with whim from either side. Both Huawei and Nokia stand out with notably broad "inventor portfolios" (considerable high co-patent numbers with several partners).. From an inventor perspective, patterns akin to those depicted in Figure 69 emerge, primarily featuring German inventors, but also encompassing contributions from Swedish, Finnish, French, and British inventors. A point of intrigue is the distinct geographical preferences of certain Chinese companies: TCL, a telecommunications giant, appears to have a concentrated collaboration focus on Denmark, resulting in 102 co-patents. Similarly, Geely, the automotive company, displays a pronounced collaborative inclination towards Sweden, evidenced by over 200 joint patents.

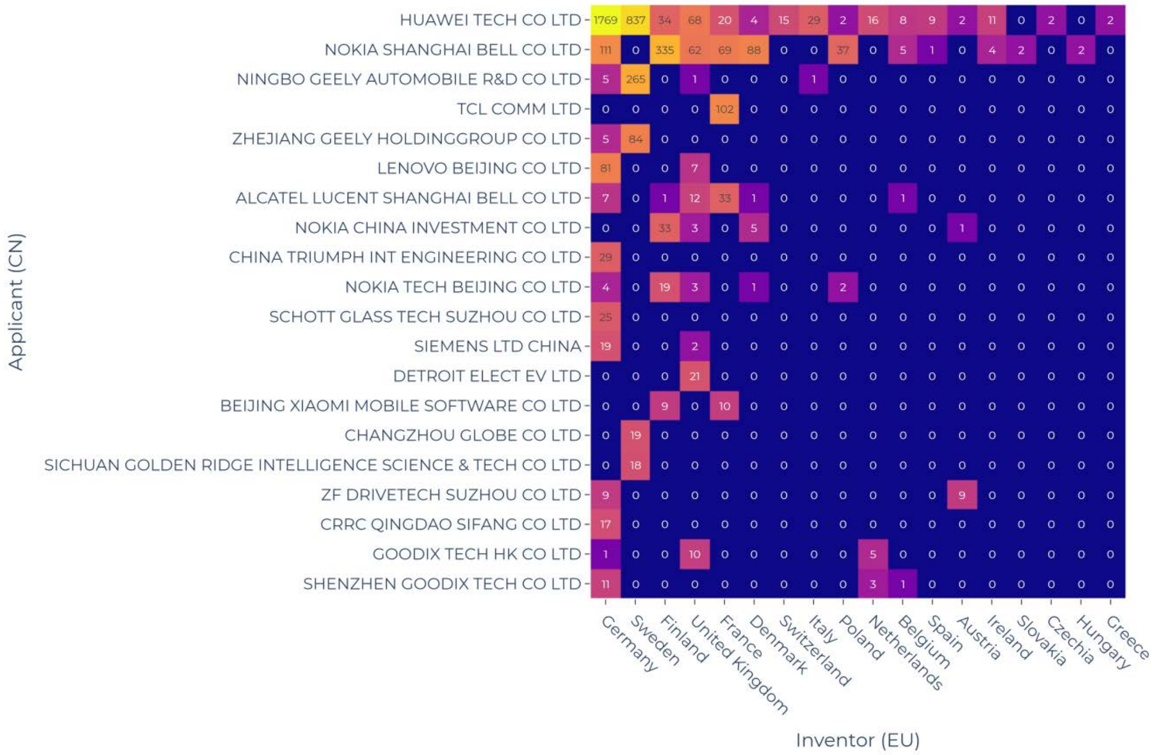


Figure 73. European inventor portfolio of the top-20 Chinese applicants: number of co-applications having at least one inventor from the respective EU27/AC country

4.2.4 Co-patents by technology/industry (leveraging the IPC taxonomy)

The International Patent Classification system is a hierarchical system of symbols for the classification of patents according to the different areas of technology to which they pertain, managed by the World Intellectual Property Organization. The IPC is organised into a multi-tiered structure that includes (in descending hierarchy): Sections, Classes, Subclasses, Groups. In the following we are focusing on the broadest level of hierarchy, that is, IPC sections, corresponding to a specific field of technology. These are:

- A: Human Necessities
- B: Performing Operations; Transporting
- C: Chemistry; Metallurgy
- D: Textiles; Paper
- E: Fixed Constructions
- F: Mechanical Engineering; Lighting; Heating; Weapons; Blasting
- G: Physics
- H: Electricity

It must be noted that patents can be associated with multiple IPC symbols at the same time, indicating that they cover innovations in more than one technological area. Thus, the IPC system is not exclusive, and a single patent can span multiple categories of technology.

In Figure 74 the distribution and annual progression of Chinese-EU27/AC collaborative patents across IPC sections is shown. A key observation is the significant co-patent concentration in the

Electricity sector, boasting 6738 joint patents. This is trailed by Physics, with 2594 co-patents, and the Operations & Transporting section, accounting for 1482 co-patents. Over the years, the filing rate for co-patents associated with Electricity has seen consistent growth, roughly doubling in scale, mirroring the trend seen in the Human Necessities sector. Concurrently, there's been a more pronounced uptick in the sections of Physics, Operations & Transporting, Chemistry & Metallurgy, and Engineering. areas All of these sectors witnessed a 2 to 3-fold surge in co-patent filings since 2020.

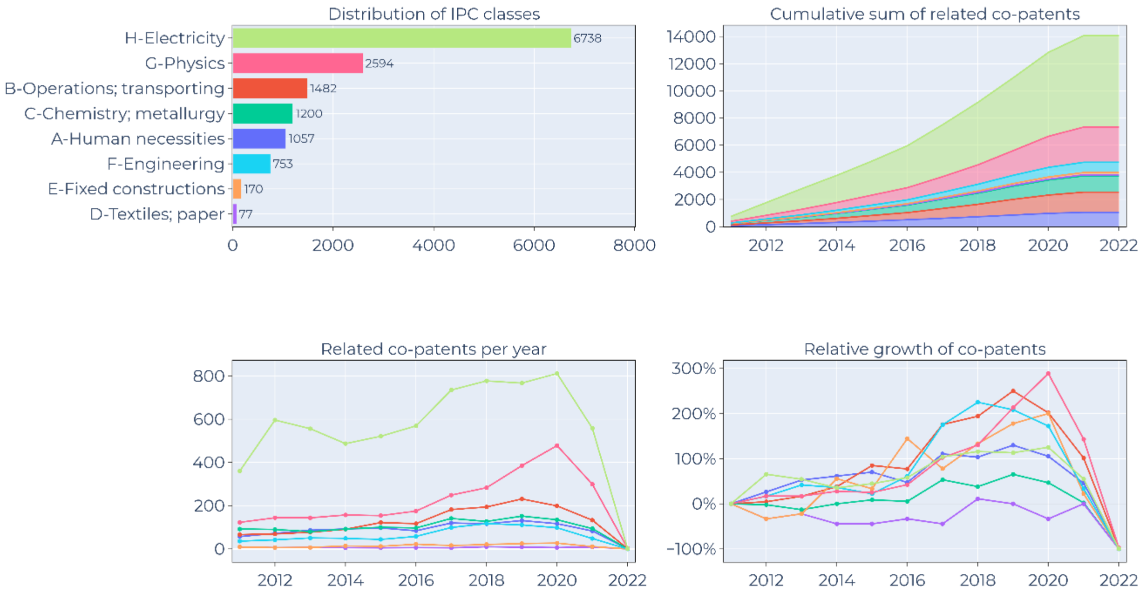


Figure 74. Detailed distribution of classes and respective tendencies of patent co-applications based on IPC patent classification. From left to right, top to bottom: overall distribution of IPC classes; cumulative sum of co-applications; annual co-application submissions and relative growth in annual submission of co-applications, indexed to 2011

In the final segment of our analysis, we provide a concise overview of the predominant distribution trends. Our attention is primarily directed towards the distribution patterns of application authorities, as well as the contributions made by inventors and applicants. For a direct comparison with the comprehensive trends, readers are referred to Figure 62 for application authorities, Figure 69 for inventors, and Figure 68 for applicants. Furthermore, we illuminate the principal applicant stakeholders within each IPC section. This serves to deepen our understanding of the specific fields that are at the forefront of co-patenting activities between China and the EU27/AC in the specific technology sector.

4.2.5 Human necessities (A)

The section of Human necessities covers inventions related to daily life and human health, including food, agriculture, clothing, and medical equipment. We found 6738 co-patents pertaining to this scope.

For application authorities (Figure 75), WIPO remains the dominant organisation, accounting for 69.3% of all patent applications in this sector. The European Patent Office follows with 8.6%, while national patent offices like the United Kingdom (6.9%), Germany (6.0%), and France (5.5%) have a somewhat smaller share (though still slightly higher than the average).

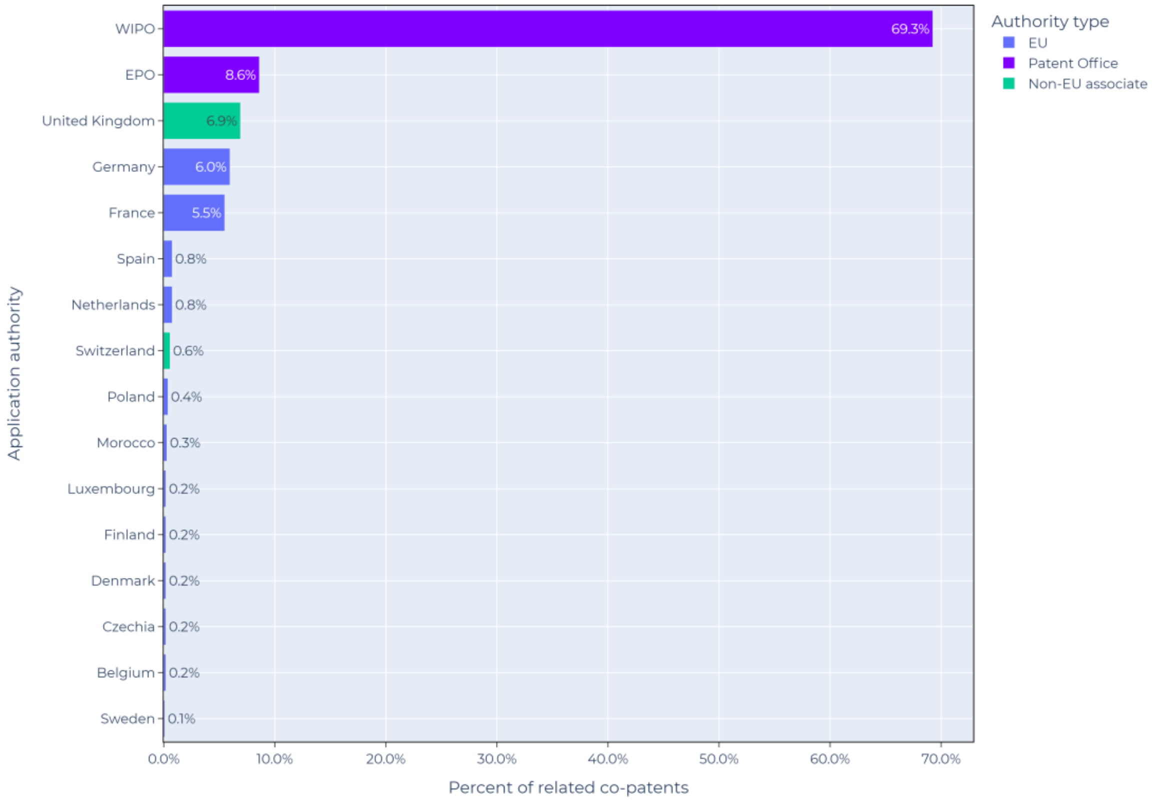


Figure 75. Percentage distribution of co-patents in Human Necessities by application authority

In terms of inventorship by country (Figure 76), China's dominance is greatly pronounced, with a contribution of 88.8%. Among EU27/AC countries, Germany leads with 16.0%, followed by France (9.0%), the United Kingdom (7.9%), Switzerland (6.3%), and Sweden (5.3%).

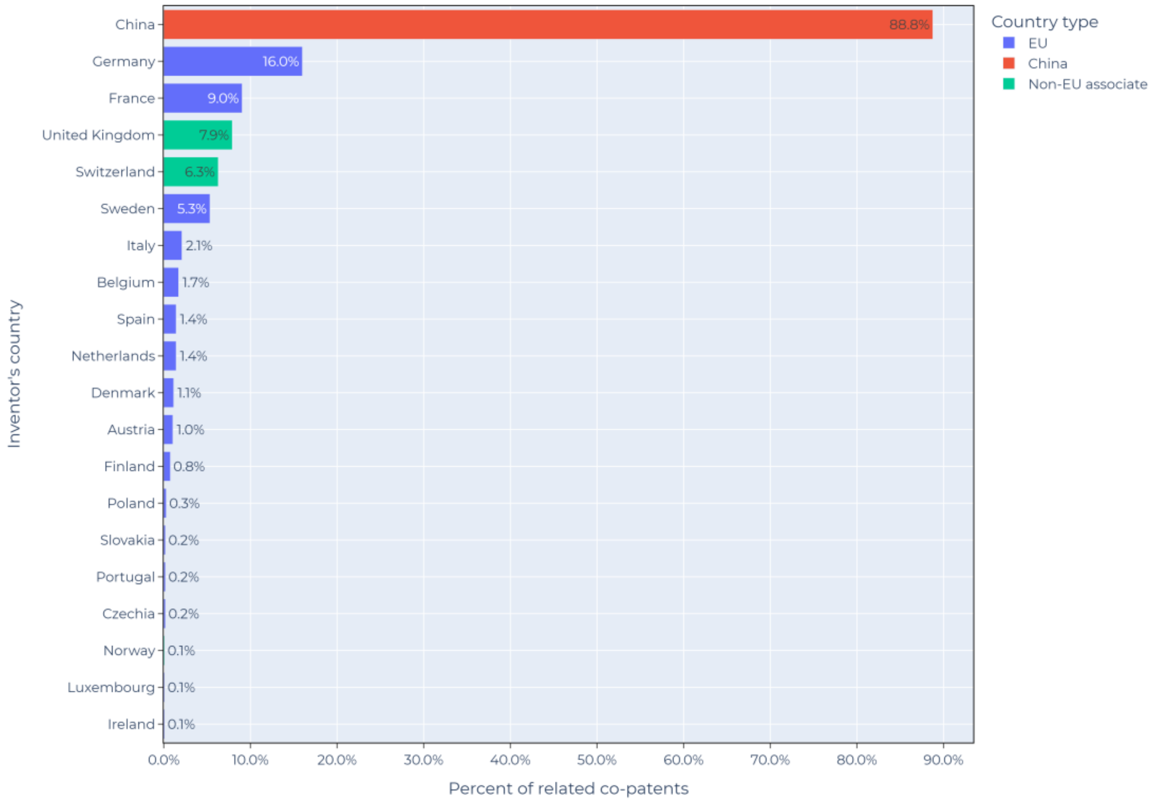


Figure 76. Percentage distribution of co-patents in Human Necessities by inventor country (with at least one applicant from the respective countries)

Diving into the data on leading countries with applications in Human Necessities (Figure 77), China emerges as the predominant contributor with 71.9% of co-patents. European countries like France (32.4%), Germany (23.7%), Switzerland (9.8%), the United Kingdom (7.9%), and the Netherlands (4.1%) account for considerable shares too.

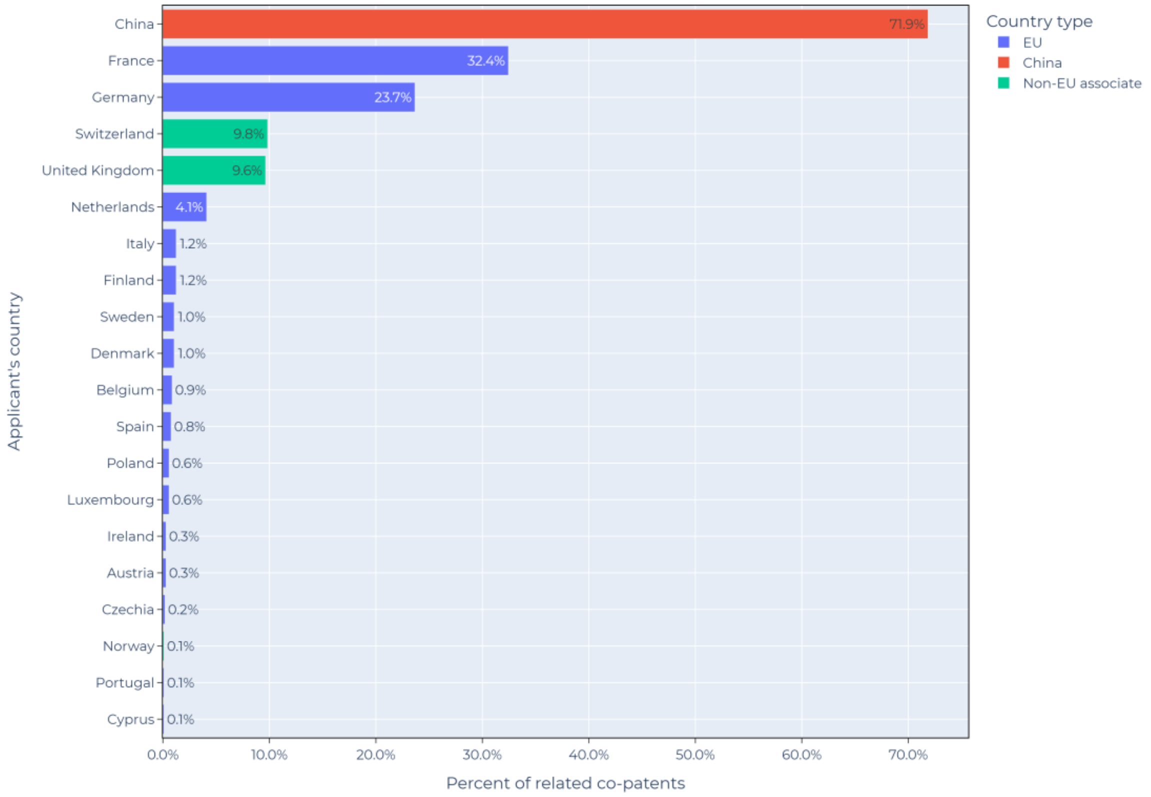


Figure 77. Percentage distribution of co-patents in Human Necessities by applicant country (with at least one applicant from the respective countries)

Which legal entities from the EU27/AC are mostly involved in the Human Necessities sector? Figure 78 provides an answer. L'Oreal, NESTEC SA (part of the Nestlé group) and BEIERSDORF AG lead this field in Europe. In China (Figure 79), the BEIERSDORF DAILY CHEMICAL WUHAN CO LTD and FRESENIUS MEDICAL CARE R&D SHANGHAI CO LTD are at the top. In terms of sectors represented, the companies listed operate in the skincare, medical devices, food technology, and telecommunications industry.

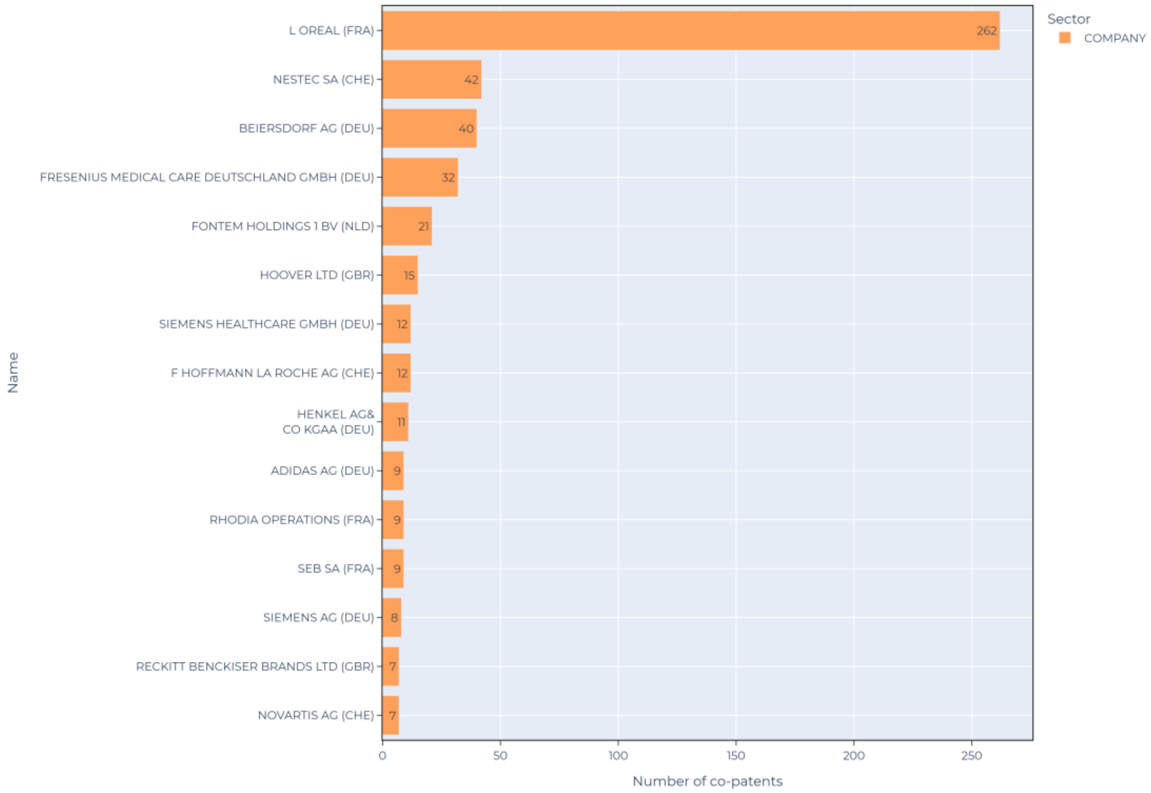


Figure 78. Top-15 EU27/AC applicants collaborating on co-patents in Human Necessities with Chinese participants.

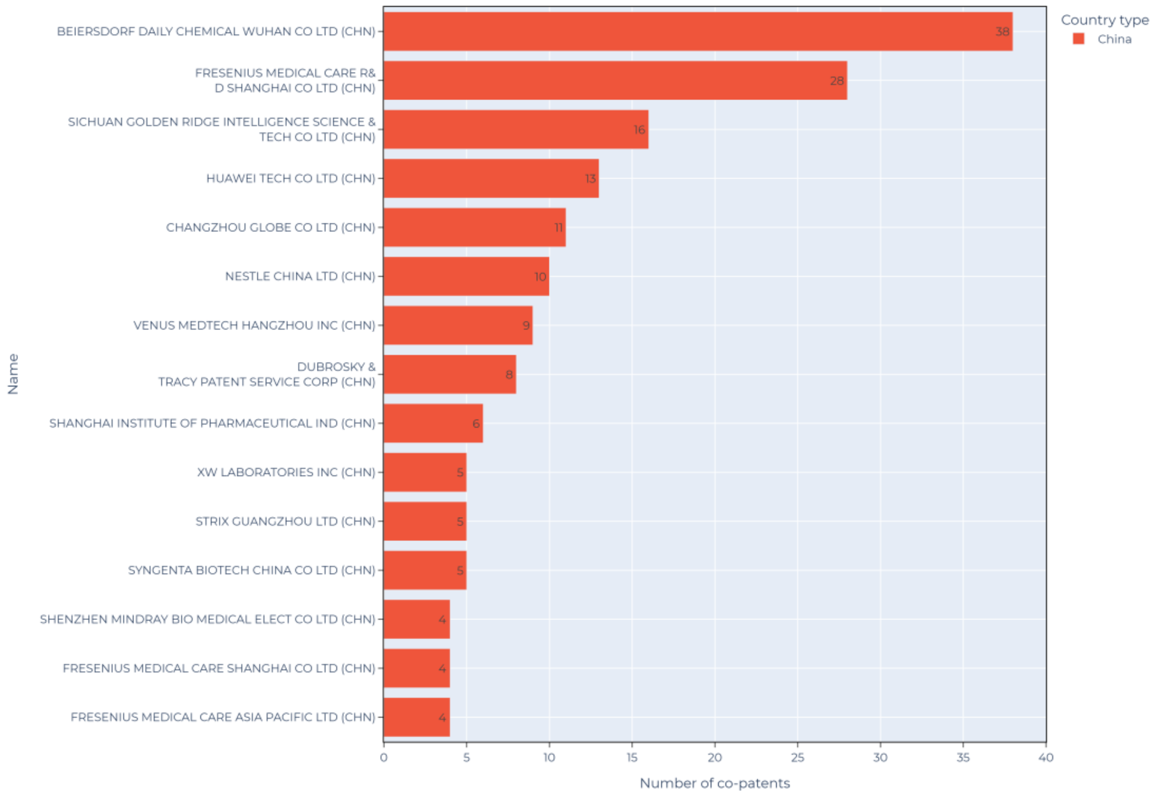


Figure 79. Top-15 Chinese applicants collaborating on co-patents in Human Necessities with EU27/AC participants.

4.2.6 Operations; transporting (B)

The IPC section of Operations; transporting pertains to processes, tools, and equipment for manufacturing, as well as transportation methods and vehicles. In our scope of data this section boasted 1482 co-patents.

For the application authorities (Figure 80), most co-patents were again filed with WIPO, also if the 47.5% in Operations;transporting are lagging behind the 78.8% of overall co-patents filed with WIPO. In direct contrast to this, the EPO has gained more popularity in this sector (20%) vis-à-vis its overall share in co-patent filings (8.7%)., Among the national patent offices, Germany stands out with its contribution almost tripling to 16.6% in Operations;transporting compared to the overall 5.6%.

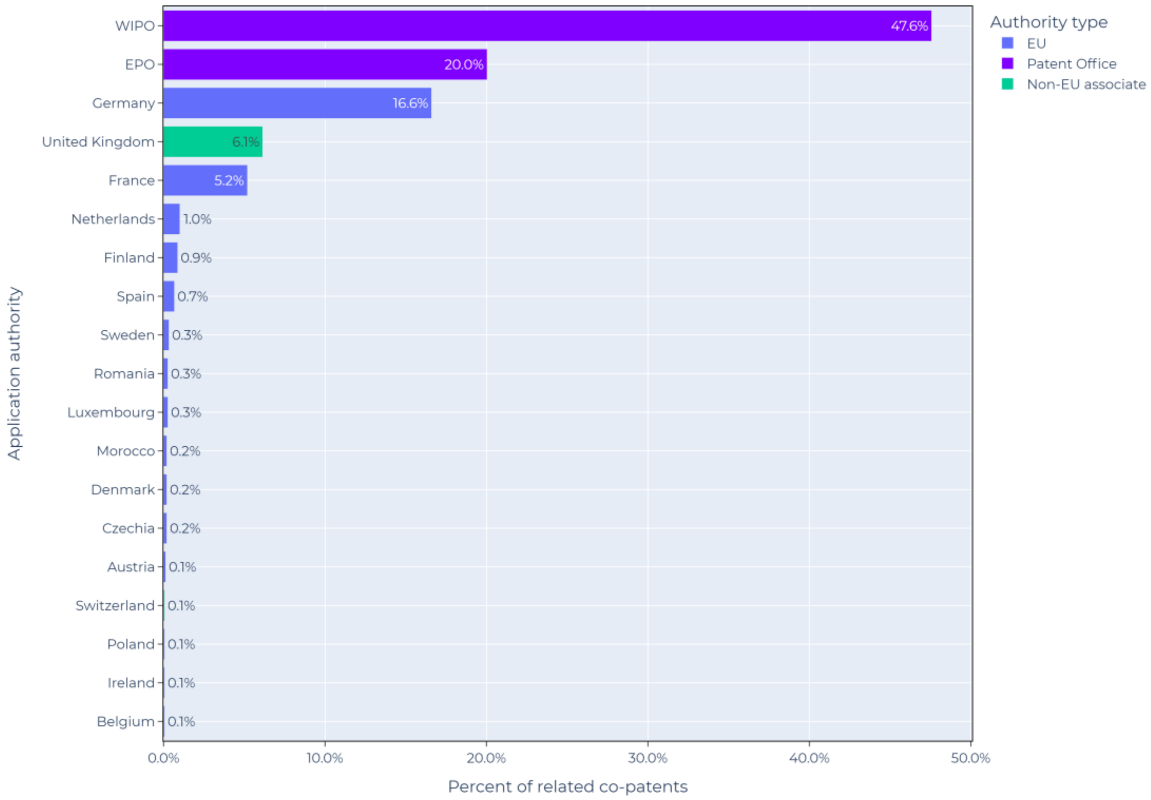


Figure 80 Percentage distribution of co-patents in Operations; transporting by application authority

The inventorship by country (Figure 81) results in a slightly different picture. While China remains dominant with 76.1%, this is only a bit higher than the overall dataset's 71.2%. Germany, however, has seen a slight dip, contributing 25.4% in comparison to the overall 28.6%.

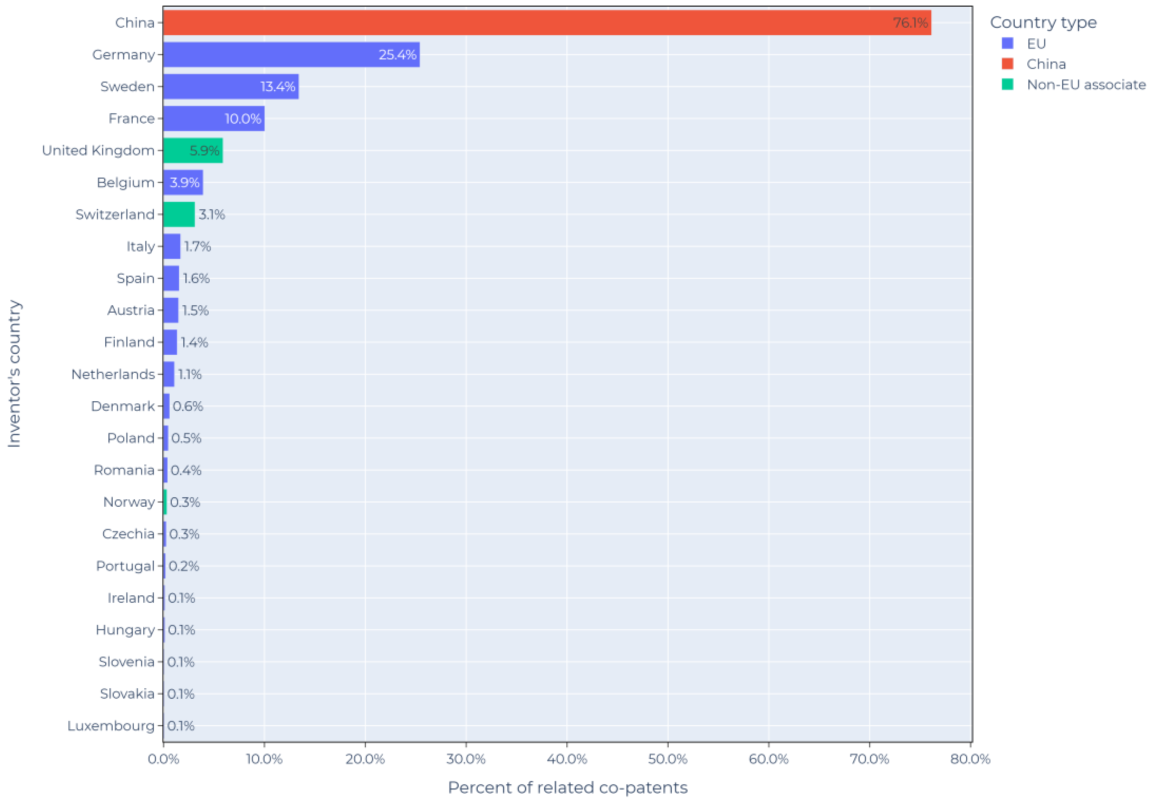


Figure 81 Percentage distribution of co-patents in Operations; transporting by inventor country (with at least one applicant from the respective countries)

In terms of countries (Figure 82), 65.5% of co-patents in this sector were filed in China (which is a slight increase compared to 57.5% of all co-patents filed in China). Germany, with 38.0%, has nearly doubled its share here compared to overall patent applications (20.4%). France, with 12.8%, and Switzerland, with 13.0%, have also seen significant increases compared to overall figures of 9.8% and 6.4% respectively.

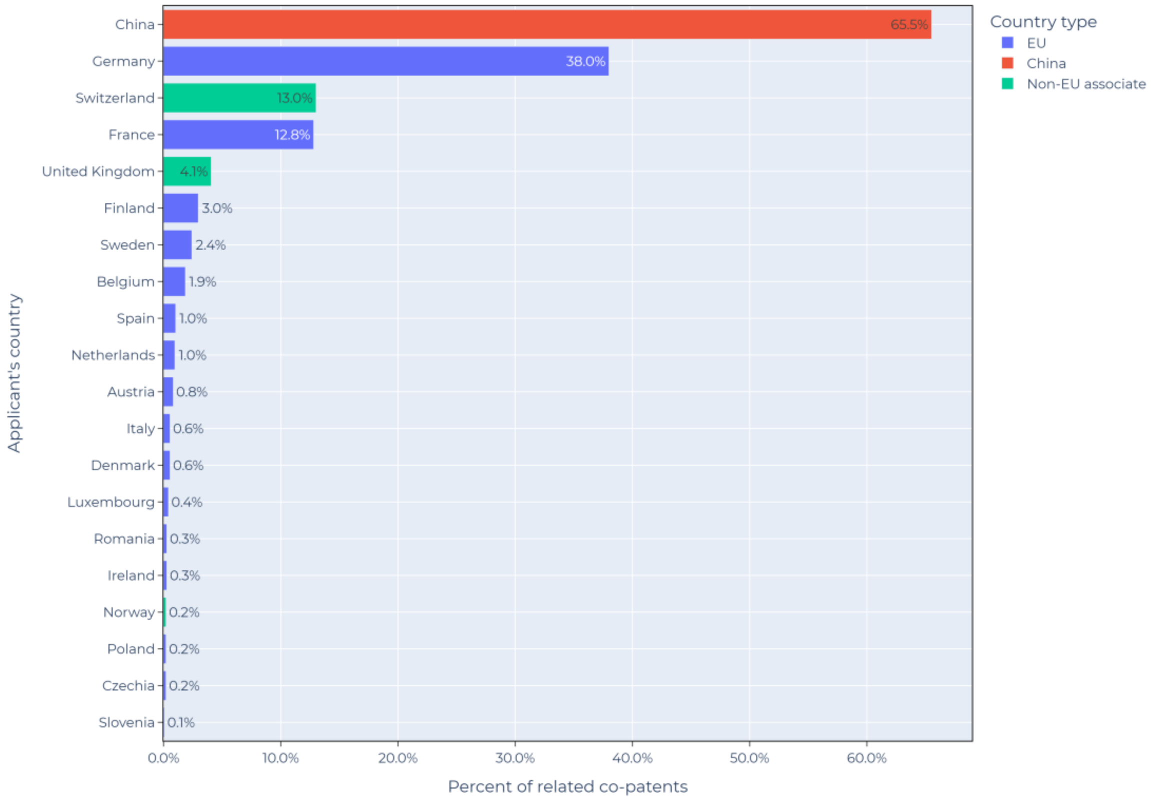


Figure 82. Percentage distribution of co-patents in Operations; transporting by applicant country (with at least one applicant from the respective countries)

For the EU27/AC, ABB SCHWEIZ AG (Energy and Automation), SCHAEFFLER TECH AG&CO KG (Automotive supply), and ROBERT BOSCH GMBH (Consumer goods; Automotive supply etc.) are the most important corporations represented in this sector (Figure 83). On the Chinese side (Figure 84), the overwhelming presence of firms like Geely and (to a lesser extent) Huawei indicates a strong innovation cooperation in the areas of transport technologies, efficient operations, and smart logistics.

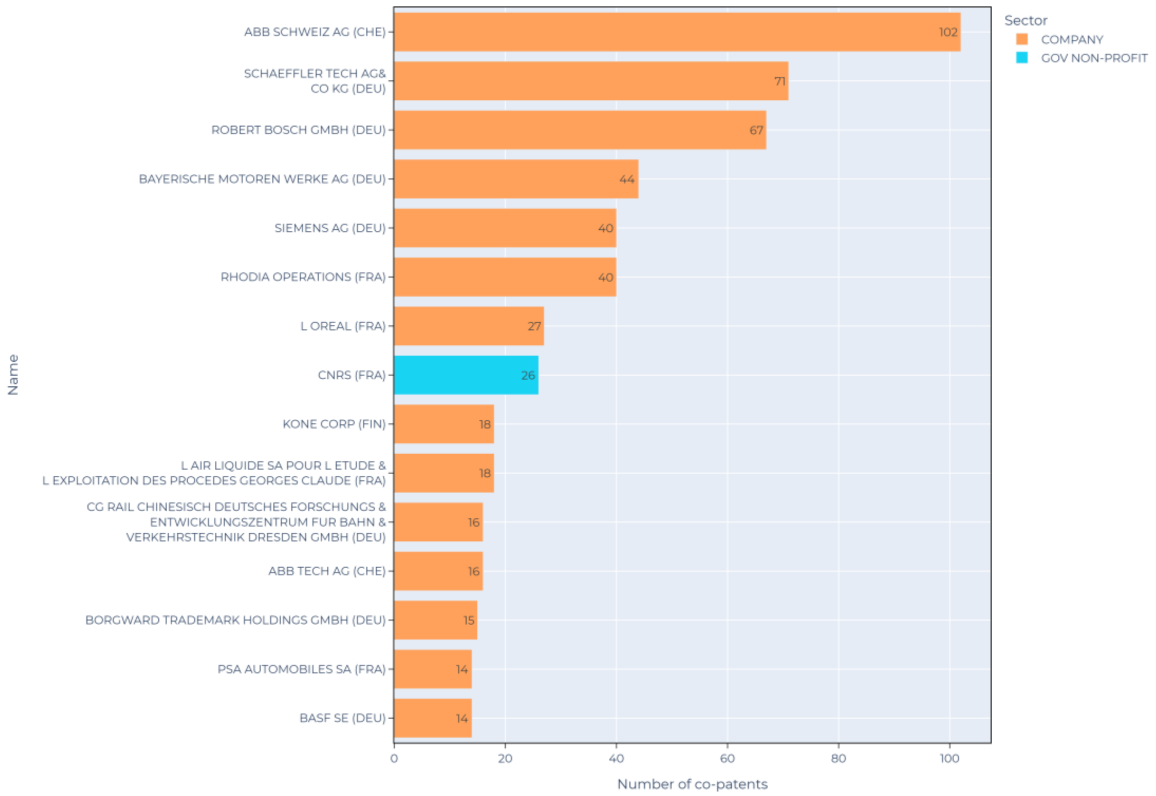


Figure 83 Top-15 EU27/AC applicants collaborating on co-patents in Operations; transporting with Chinese participants.

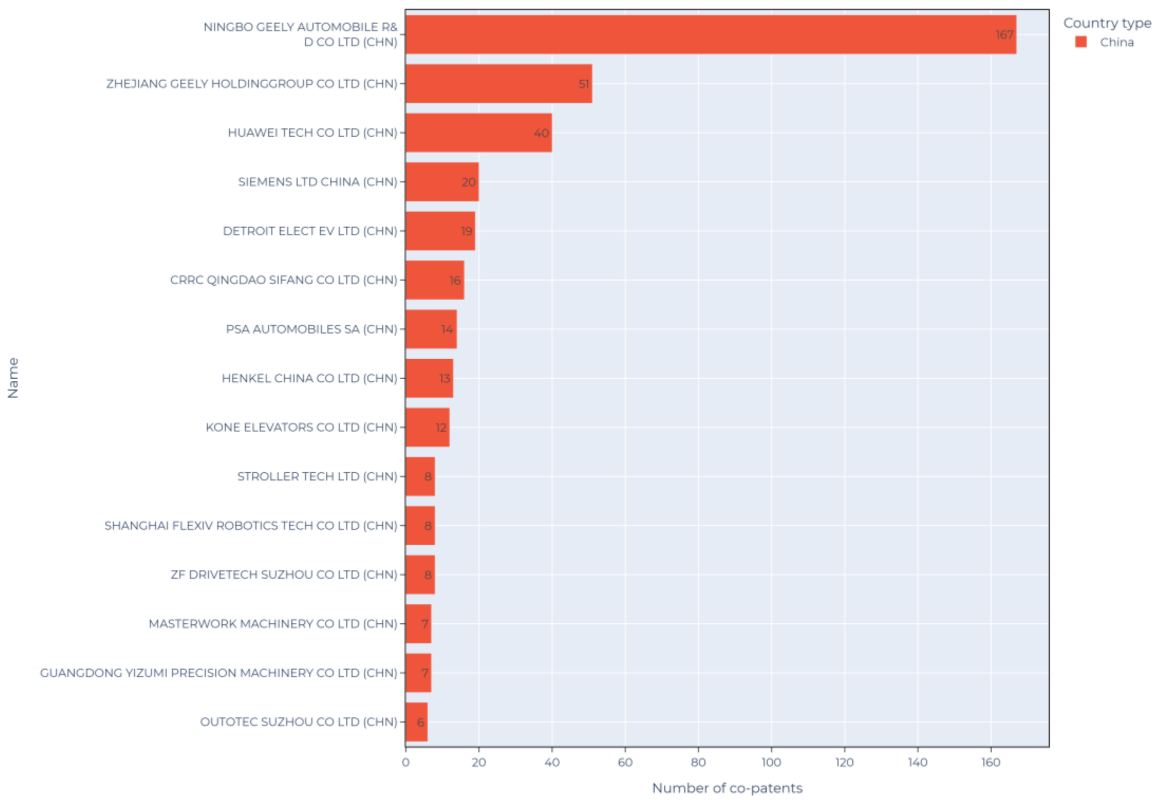


Figure 84. Top-15 Chinese applicants collaborating on co-patents in Operations; transporting with EU27/AC participants.

4.2.7 Chemistry; metallurgy (C)

The IPC definition of Chemistry; metallurgy encompasses chemical compositions, processes, and apparatus, as well as the extraction and processing of metals. 1200 co-patents were filtered for this section. Glancing at application authorities (Figure 85), WIPO continues to be a prominent application authority, but its contribution to this sector is less significant (68.8%) than its share of filed co-patents overall (78.8%). At the same time the EPO has shown a heightened role, with its share in this section growing to 17.2% (compared to 8.7%). Germany and France as national patent offices hold a more pronounced role in this section, with contributions of 5.3% and 4.9%, respectively.

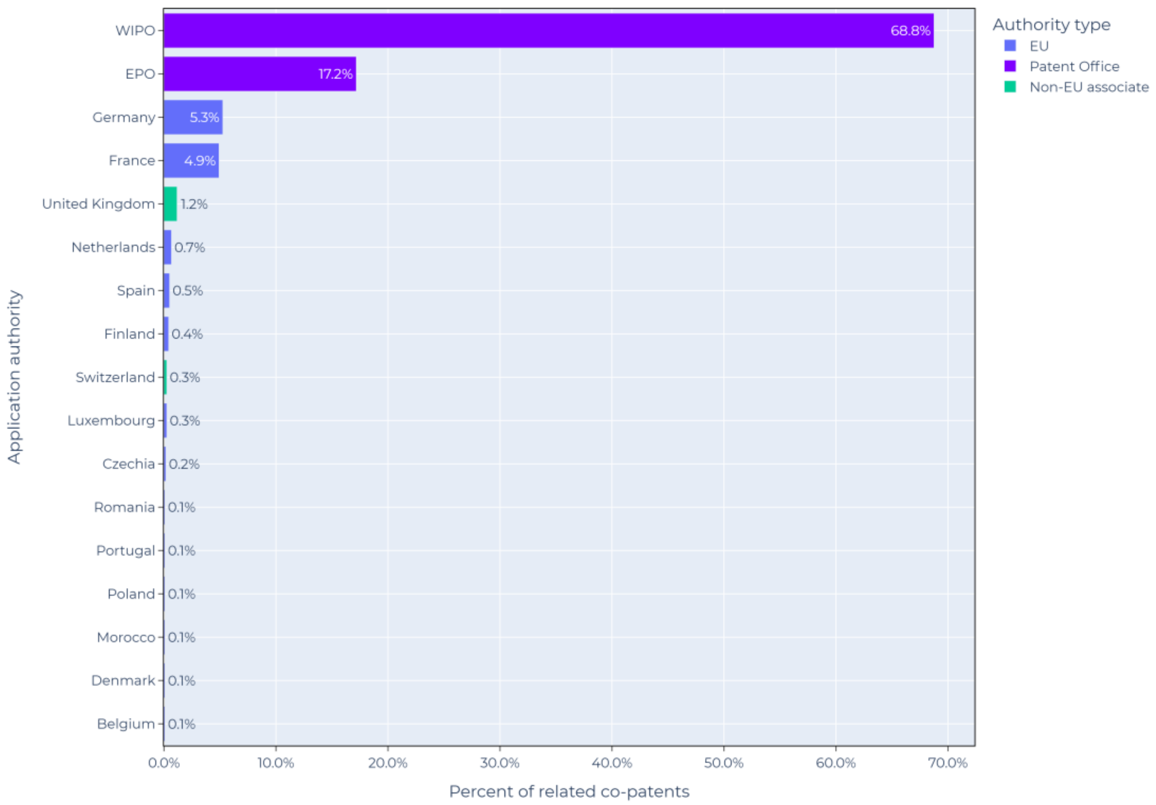


Figure 85. Percentage distribution of co-patents in Chemistry; metallurgy by application authority

Analysing the distribution of inventors (Figure 86), China showcases an overwhelming inventorship, contributing more than 90% (96.7%) of co-patent filings. Inventors from Switzerland (7.1%) and France (14.5%) are also slightly more prominent in this section. The same for Germany with 26.4%, a slight dip from the overall 28.6%.

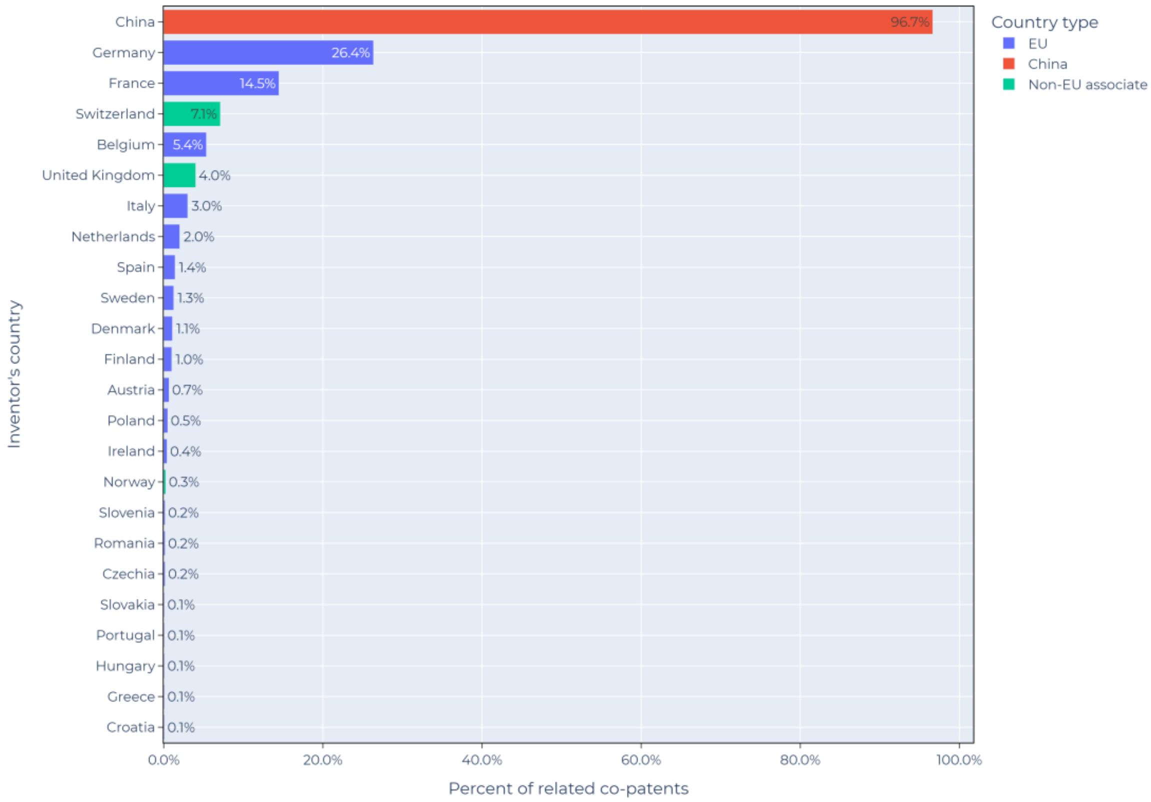


Figure 86. Percentage distribution of co-patents in Chemistry; metallurgy by inventor country (with at least one applicant from the respective countries)

From the side of applicants (Figure 87), China remains a significant applicant, representing 61.1% of all filings in this section (a slight growth from its overall share of 57.5%). Germany has intensified its contributions, standing at 38.7%, which is almost the double of its overall number of 20.4%. France has amplified its share too, contributing 22.0% compared to 9.8% overall.

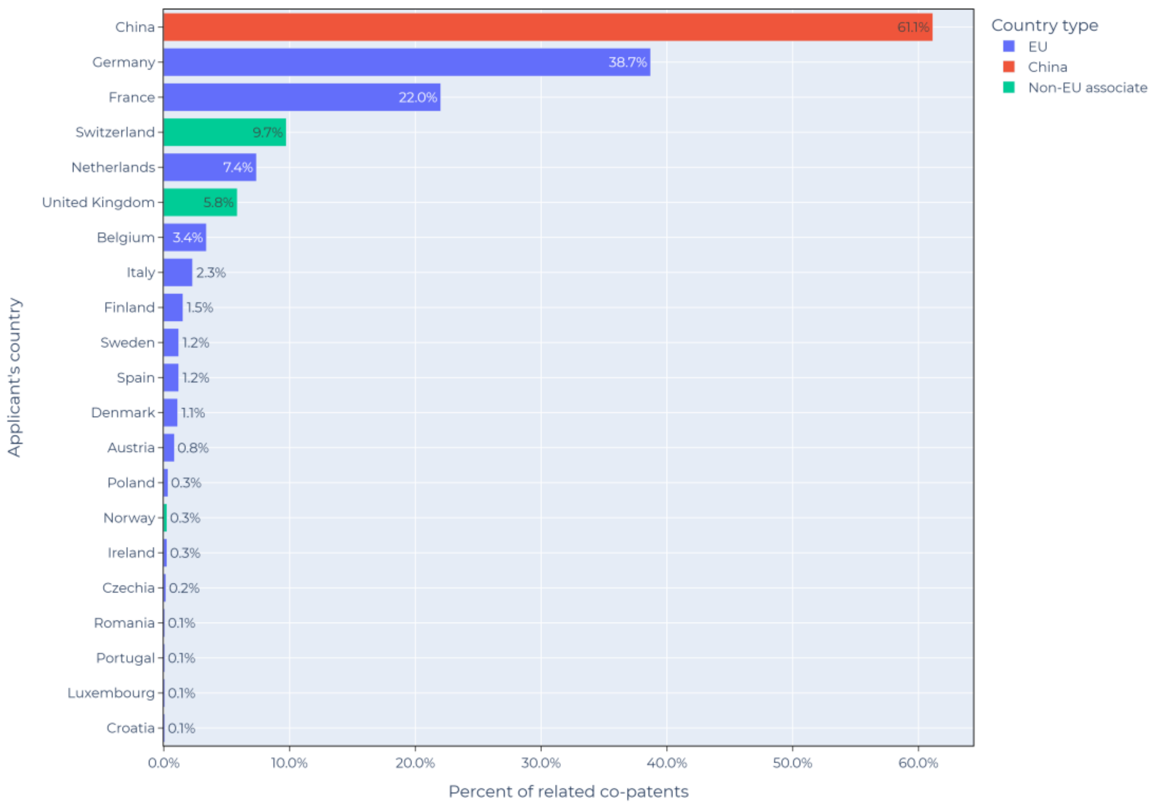


Figure 87. Percentage distribution of co-patents in Chemistry; metallurgy by applicant country (with at least one applicant from the respective countries)

From the EU27/AC, RHODIA OPERATIONS, HENKEL AG & CO KGAA, and EVONIK OPERATIONS GMBH are those commercial enterprises that dominate in this section (Figure 88). Against their industrial backgrounds, this suggests a focus in co-patenting in the fields of specialty chemicals, adhesive technologies, and advanced material sciences. The presence of CNRS underscores the emphasis on academic and research activities in this domain. On the Chinese side (Figure 89), companies such as HENKEL CHINA CO LTD, RHODIA CHINA CO LTD, and SCHOTT GLASS TECH SUZHOU CO LTD emerge as leaders, though these are obviously affiliated with European companies. This representation points towards a strong inclination in adhesive technologies, specialty chemicals, and advanced glass technologies.

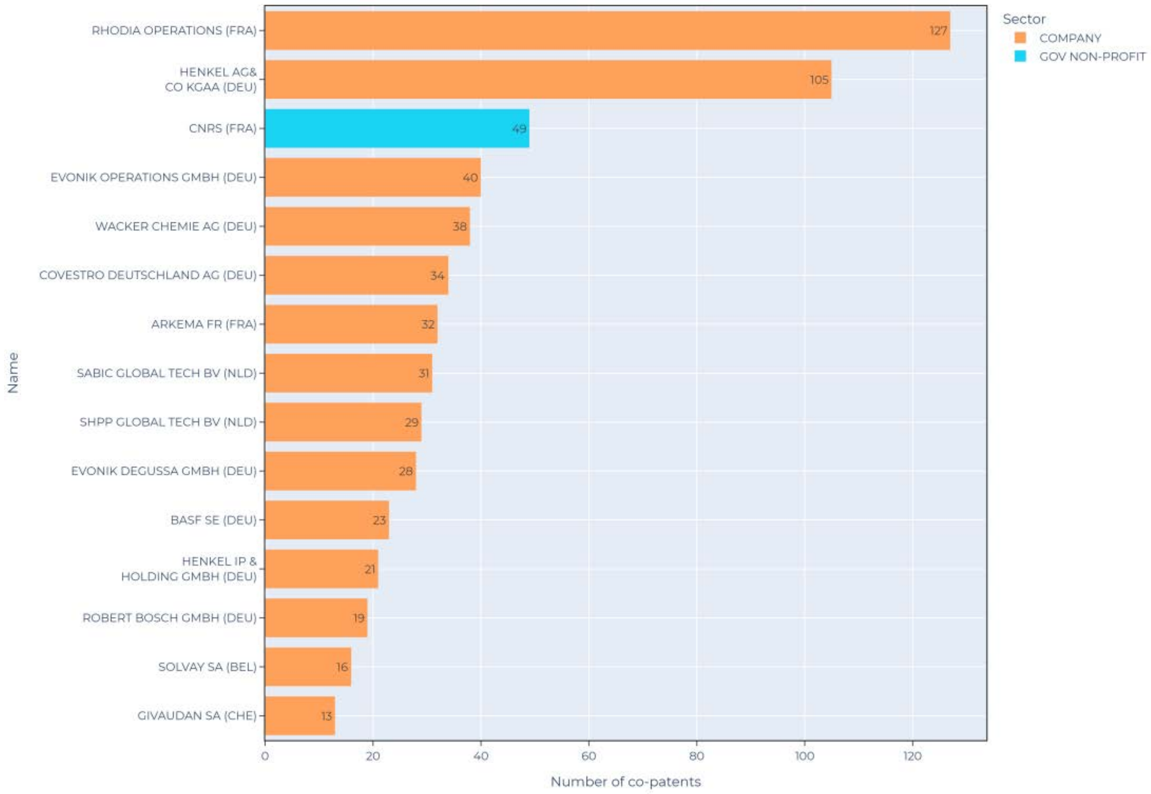


Figure 88. Top-15 EU27/AC applicants collaborating on co-patents in Chemistry; metallurgy with Chinese participants.

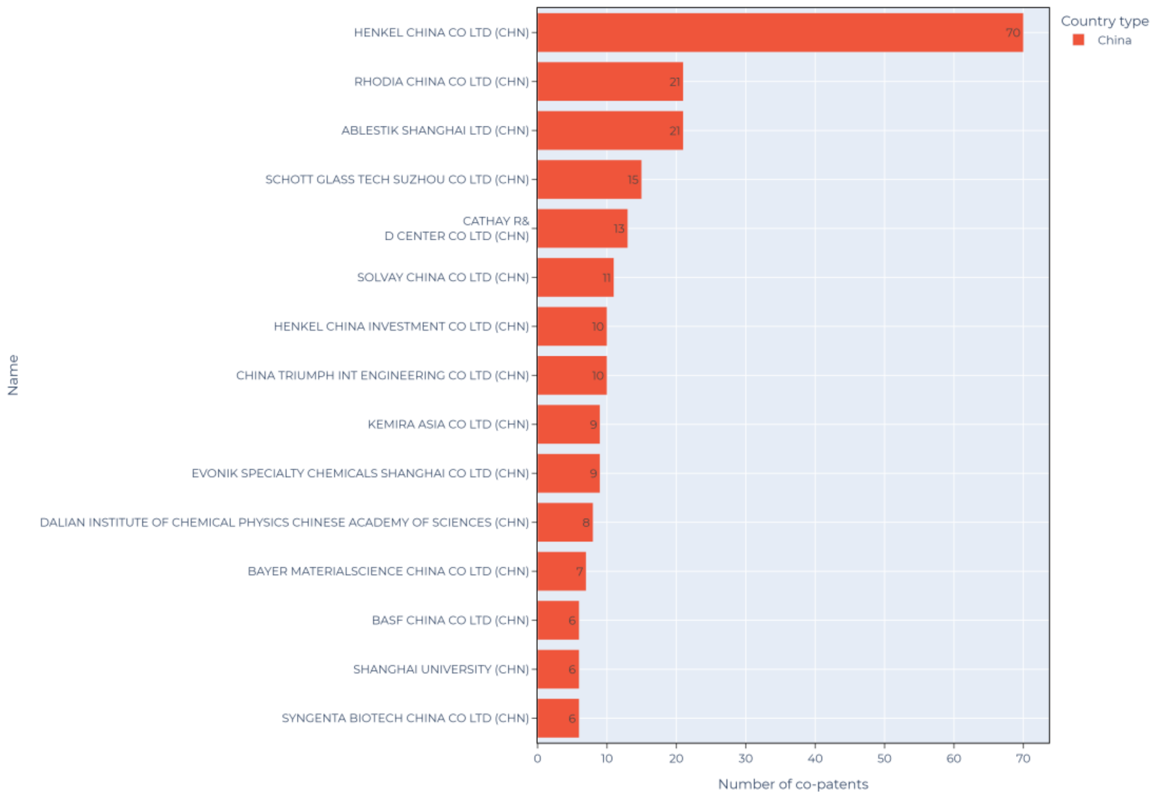


Figure 89. Top-15 Chinese applicants collaborating on co-patents in Chemistry; metallurgy with EU27/AC participants.

4.2.8 Textiles; paper (D)

The IPC section of Textiles; paper involves the production and processing of textiles, fabrics, and paper, also including associated machinery. This IPC section featured the lowest volume in our dataset, with only 77 jointly filed patents. It is very likely that the small size of this sample is responsible for several discrepancies we found in the data when doing our analysis.

For example, among application authorities (Figure 90), WIPO remains the primary fling office for this section, but its share has reduced to 57.1% compared to the overall 78.8%. EPO has expanded its role, accounting for 14.3% of applications, which is significantly up from the overall 8.7%. Germany and France, as national patent offices, have increased contributions, with 10.4% and 9.1% respectively. This diverges from their general shares of 5.6% and 2.1% in the overarching dataset.

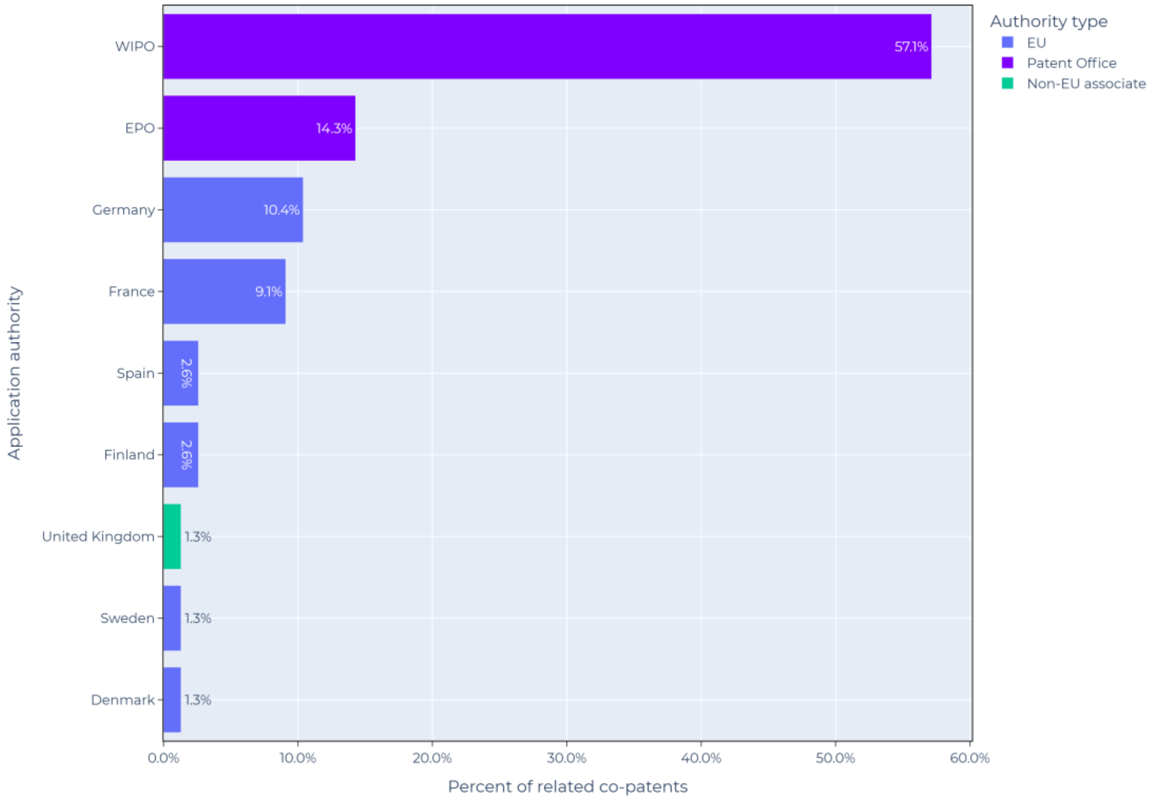


Figure 90. Percentage distribution of co-patents in Textiles; paper by application authority

Inventor-wise (on Figure 91), China maintains its dominant inventorship position with a staggering 96.1% (overall: 71.2%). Germany, with 35.1%, is slightly up from the overall 28.6%, while other countries do not differ significantly.

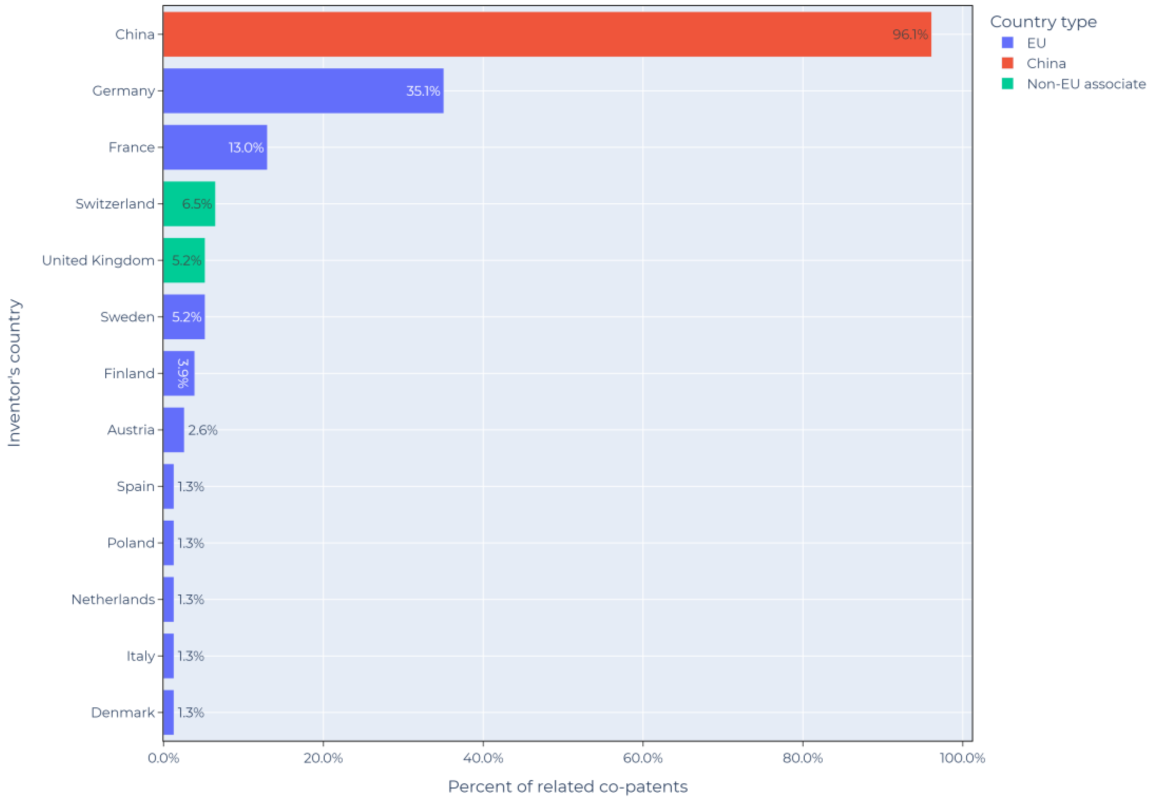


Figure 91. Percentage distribution of co-patents in Textiles; paper by inventor country (with at least one applicant from the respective countries)

Counting patents by the applicant's country (Figure 92), China remains a dominant applicant. With a share of 54.5%, it's slightly down from the overall 57.5% though. Germany has significantly increased its contributions, representing 41.6% in this section, which almost doubles its general contribution of 20.4%. France, with 14.3%, also outpaces its overall figure of 9.8%.

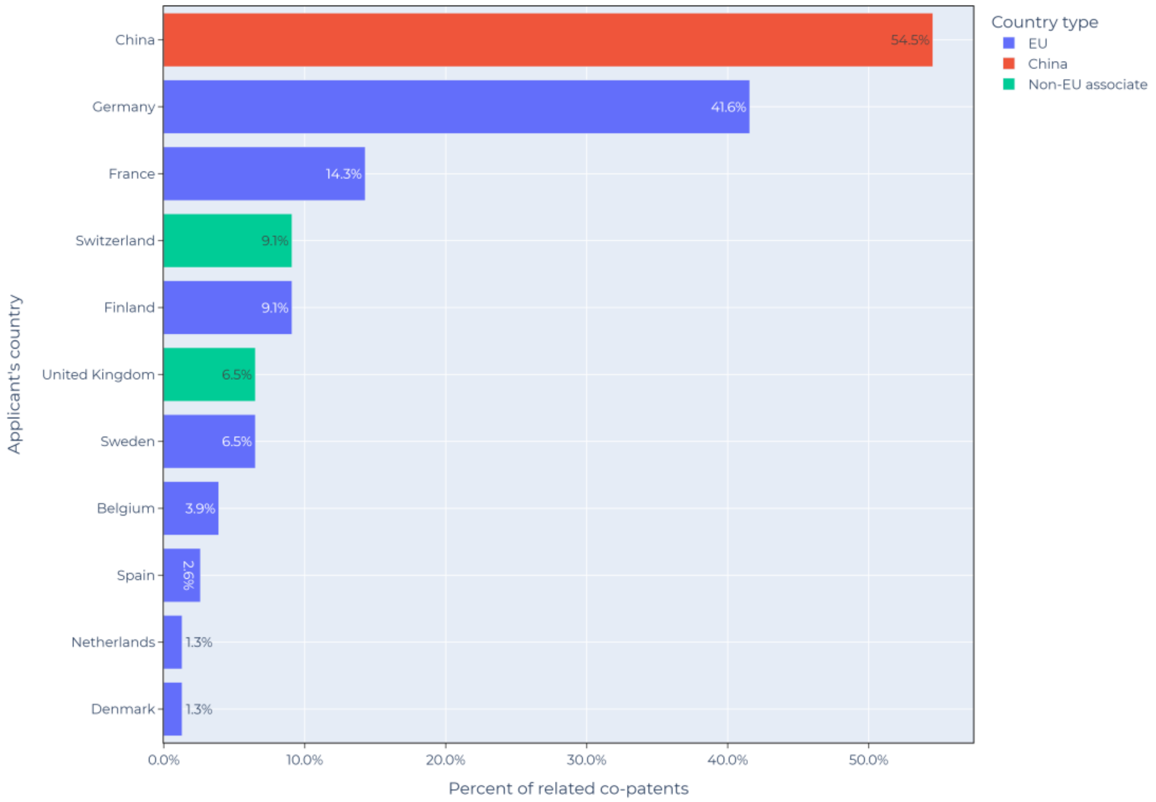


Figure 92. Percentage distribution of co-patents in Textiles; paper by applicant country (with at least one applicant from the respective countries)

Zooming in on the leading enterprises from EU27/AC involved, the top-2 companies are KEMIRA PLC, a global player in chemicals for paper and water-intensive industries, and SEB SA, a leading producer of small domestic equipment (Figure 93). WACKER CHEMIE AG and VOITH PATENT GMBH further strengthen the profile of specialty chemicals and paper technologies in the overall representation of sectors. In China (Figure 94), KEMIRA ASIA CO LTD and BAYER MATERIALSCIENCE CHINA CO LTD underline the focus on the chemicals domain, while CHINA BANKNOTE PRINTING & MINTING CORP indicates a specialised interest in advanced printing technologies, especially for secure and high-quality printing applications. It is important to note however, that the overall number of co-patents filed by these companies is still very low.

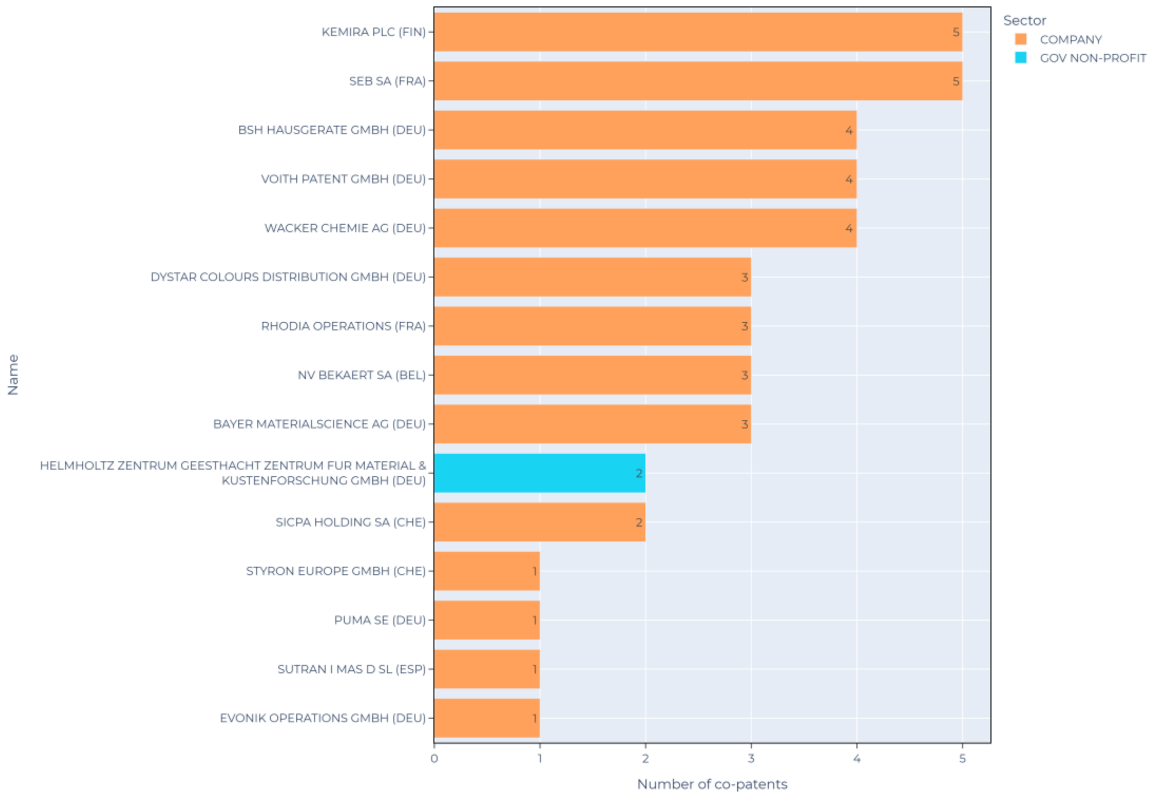


Figure 93. Top-15 EU27/AC applicants collaborating on co-patents in Textiles; paper with Chinese participants.

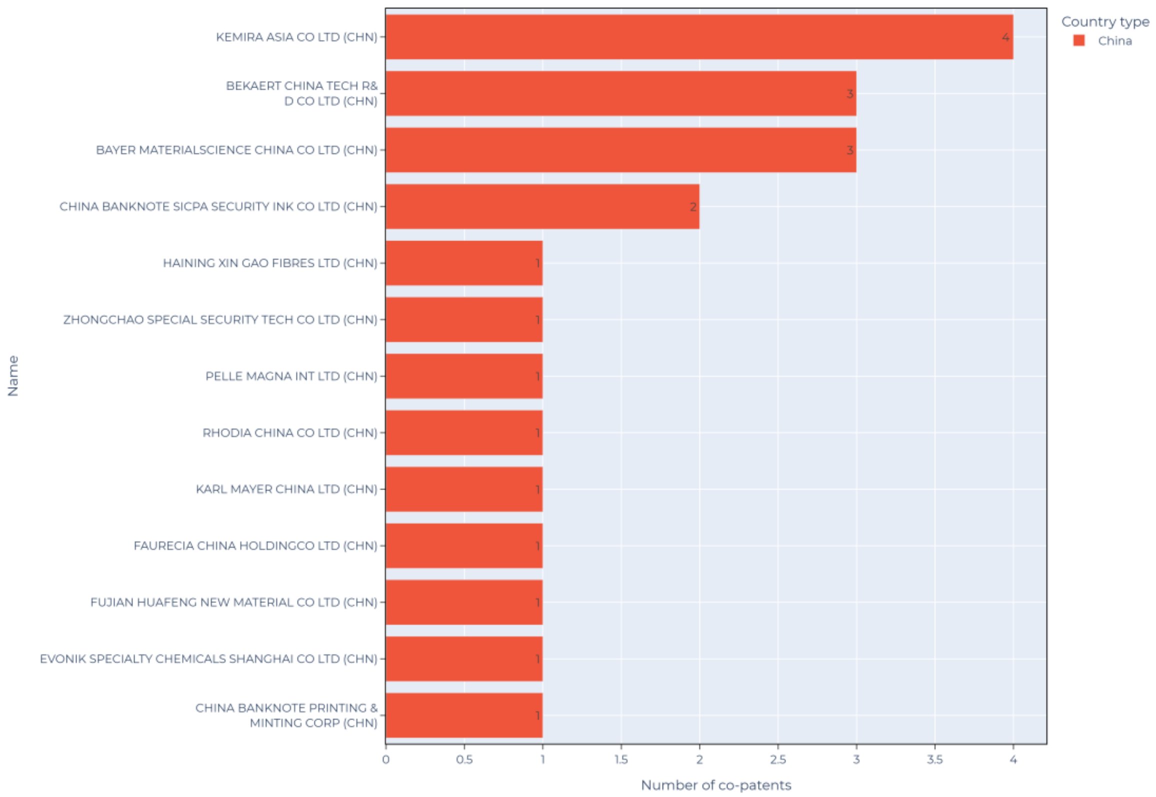


Figure 94. Top-15 Chinese applicants collaborating on co-patents in Textiles; paper with EU27/AC participants.

4.2.9 Fixed constructions (E)

The IPC section of Fixed constructions relates to buildings, bridges, roads, and other permanent structures and their construction methods, and, similar to the previous IPC section D, the sample size is rather low (170 co-patents) in this section.

For application authorities (Figure 95), WIPO, although still dominant, witnesses a reduced role in this section, with a participation of 33.5% — a notable drop from the overarching 78.8%. EPO, with 18.8%, and Germany, with 18.2%, both play more pronounced roles compared to the overall dataset. The Netherlands emerges with an 11.8% share, diverging notably from its representation in the general dataset.

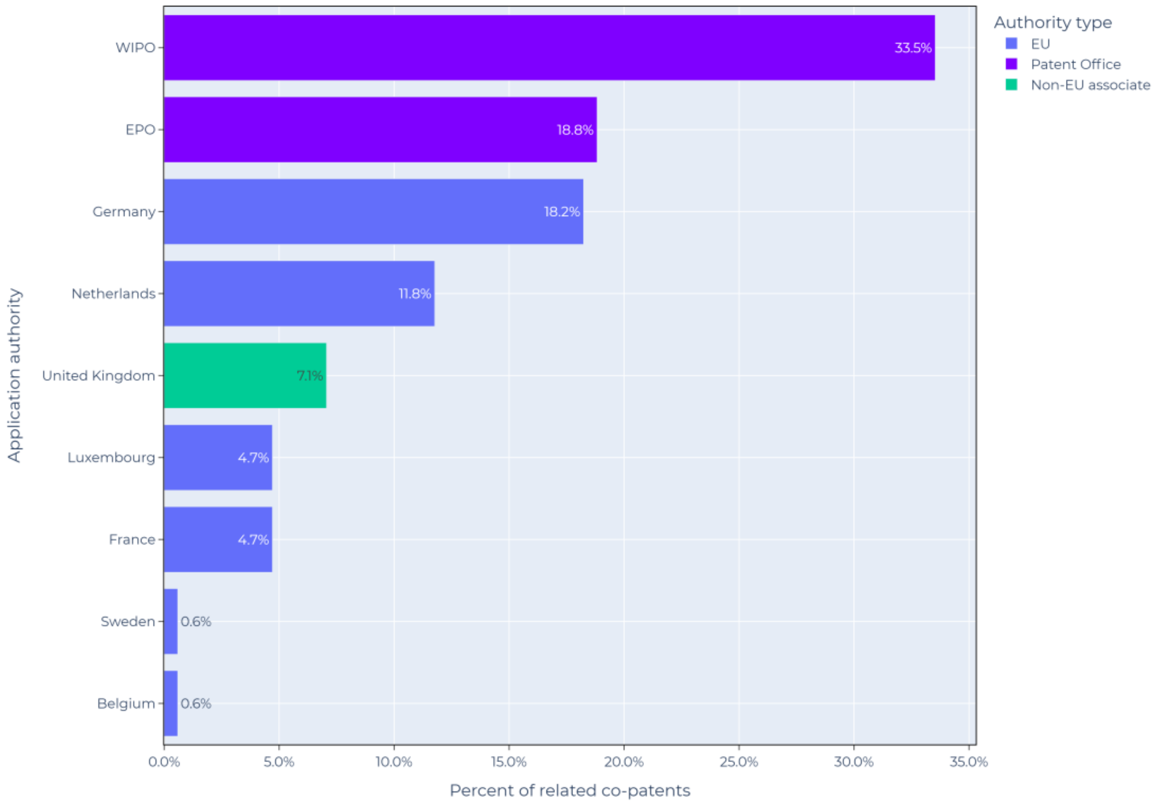


Figure 95. Percentage distribution of co-patents in Fixed constructions by application authority.

Continuing with inventorship (Figure 96), China, with a substantial 70.6% contribution, remains slightly below its overall share of 71.2%. Germany, accounting for 20.6%, has a somewhat reduced representation compared to its overall share of 28.6% as well.

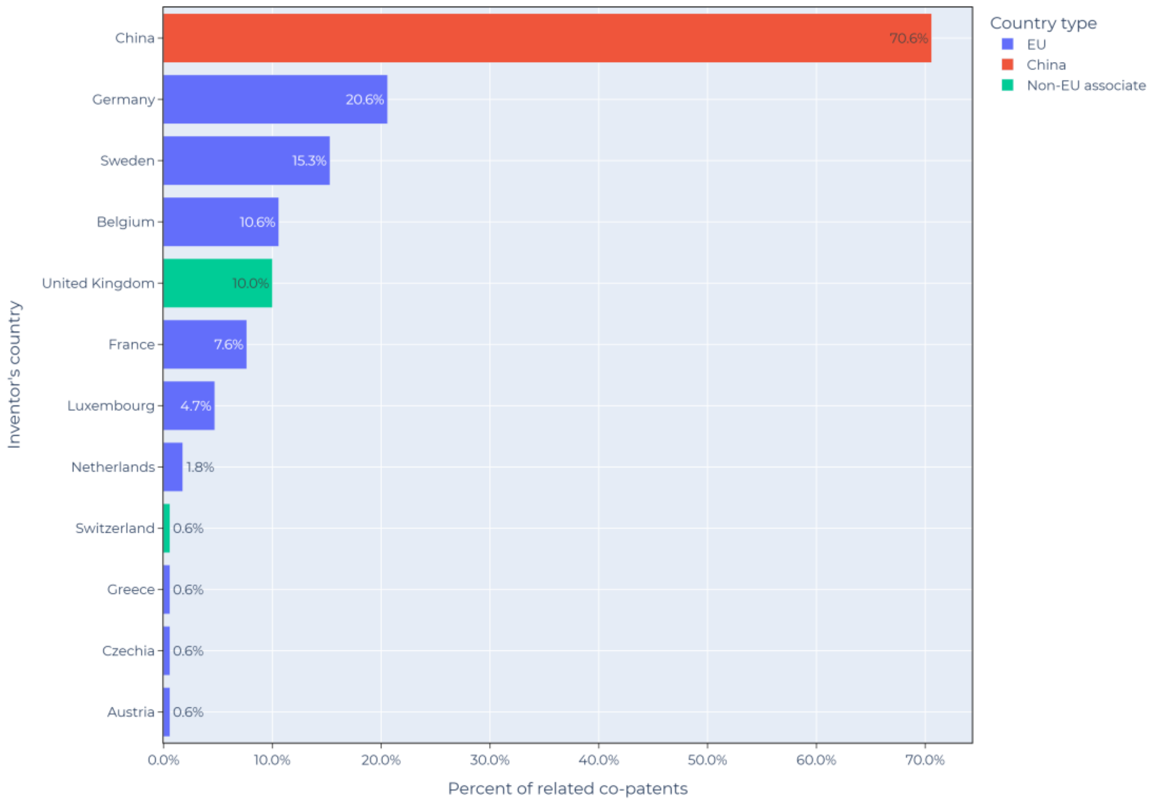


Figure 96. Percentage distribution of co-patents in Fixed constructions by inventor country (with at least one applicant from the respective countries).

In terms of applicants (Figure 97), China retains its leadership position, based on a total share of 60.6% (57.5% share overall). Germany and France exhibit increased contributions in this section too (25.8% and 17.4% respectively), and the same is true for the Netherlands (11.0%).

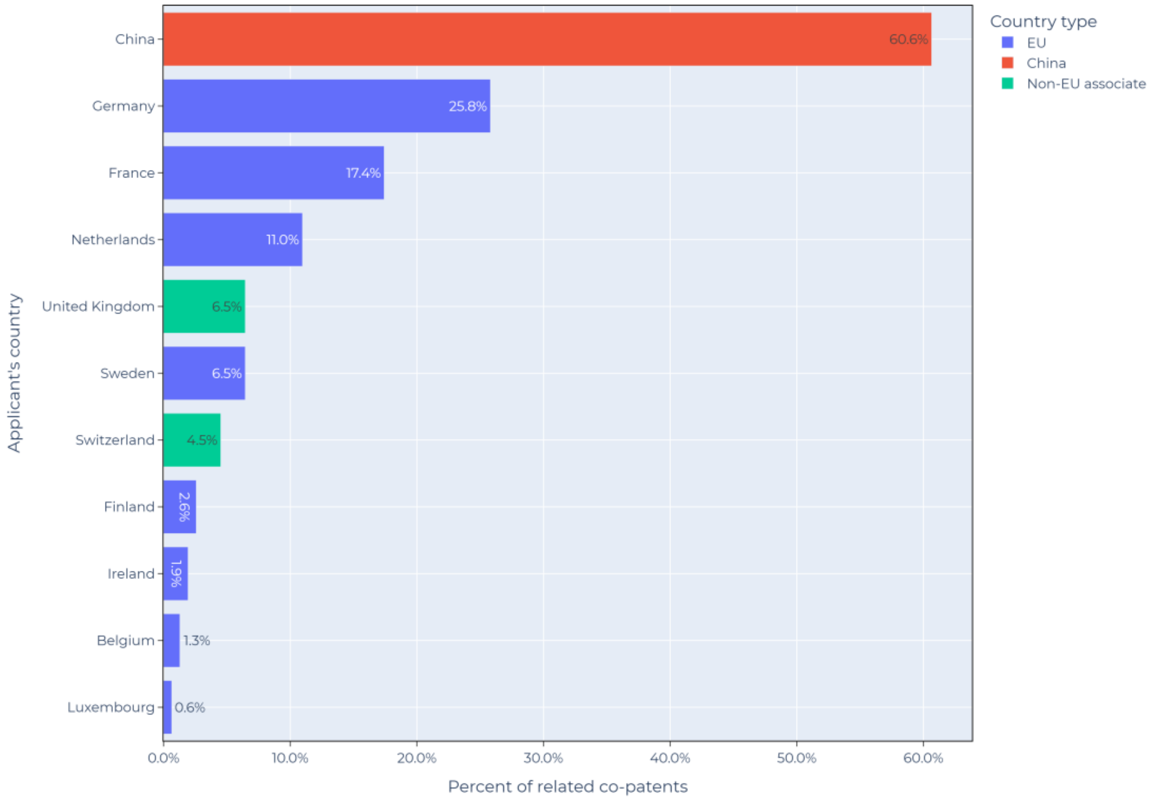


Figure 97. Percentage distribution of co-patents in Fixed constructions by applicant country (with at least one applicant from the respective countries)

As usual, next we look on the most active companies from EU27/AC having filed joint patents with Chinese partners in Fixed constructions (Figure 98). SERVICES PETROLIERS SCHLUMBERGER and GEOQUEST SYSTEMS BV suggest a patenting focus on oilfield services and geophysical exploration. VOLVO CONSTRUCTION EQUIPMENT AB probably stands for patents in construction equipment, and DORMA GMBH CO KG for patents in architectural solutions, specifically door technologies. On the Chinese side (Figure 99), corporations like the Geely Group indicate to patents in automobile research and development. The presence of HUAWEI TECH CO LTD implies an inclination towards advanced technology solutions, while companies like GUANGXI LIUGONG MACHINERY CO LTD emphasise patenting collaboration in construction machinery.

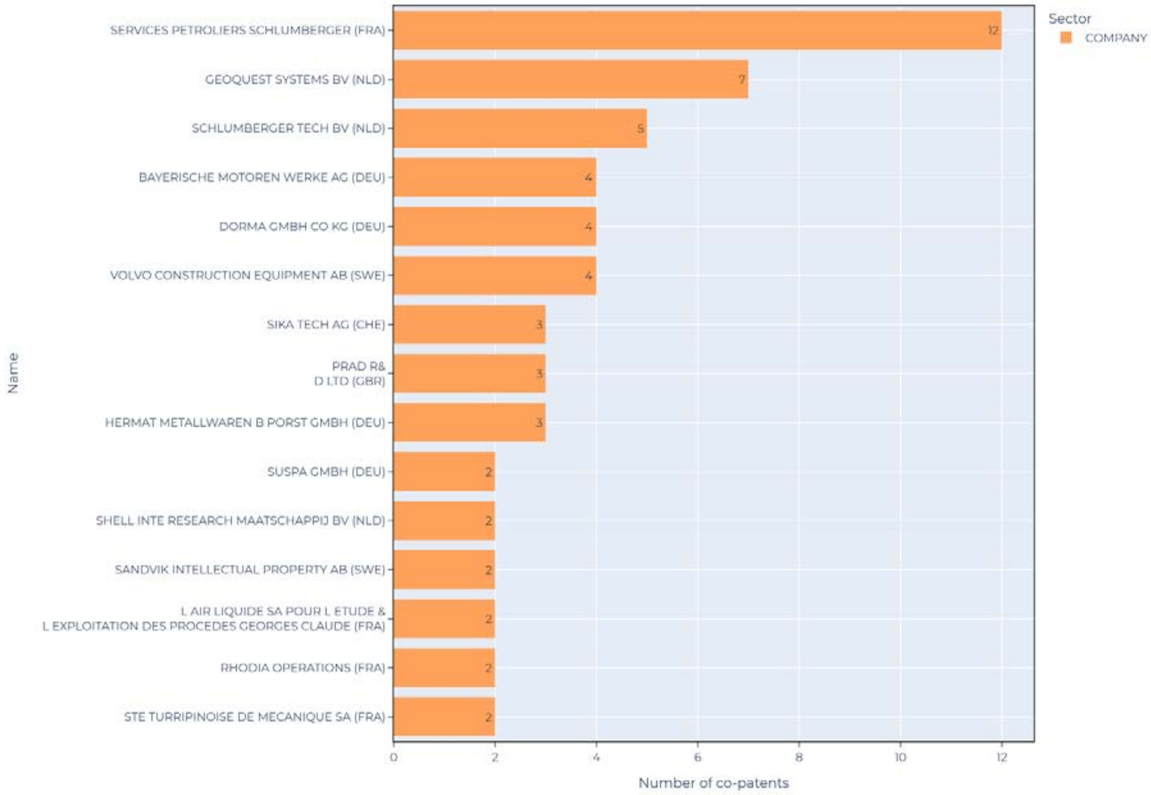


Figure 98. Top-15 EU27/AC applicants collaborating on co-patents in Fixed constructions with Chinese participants.

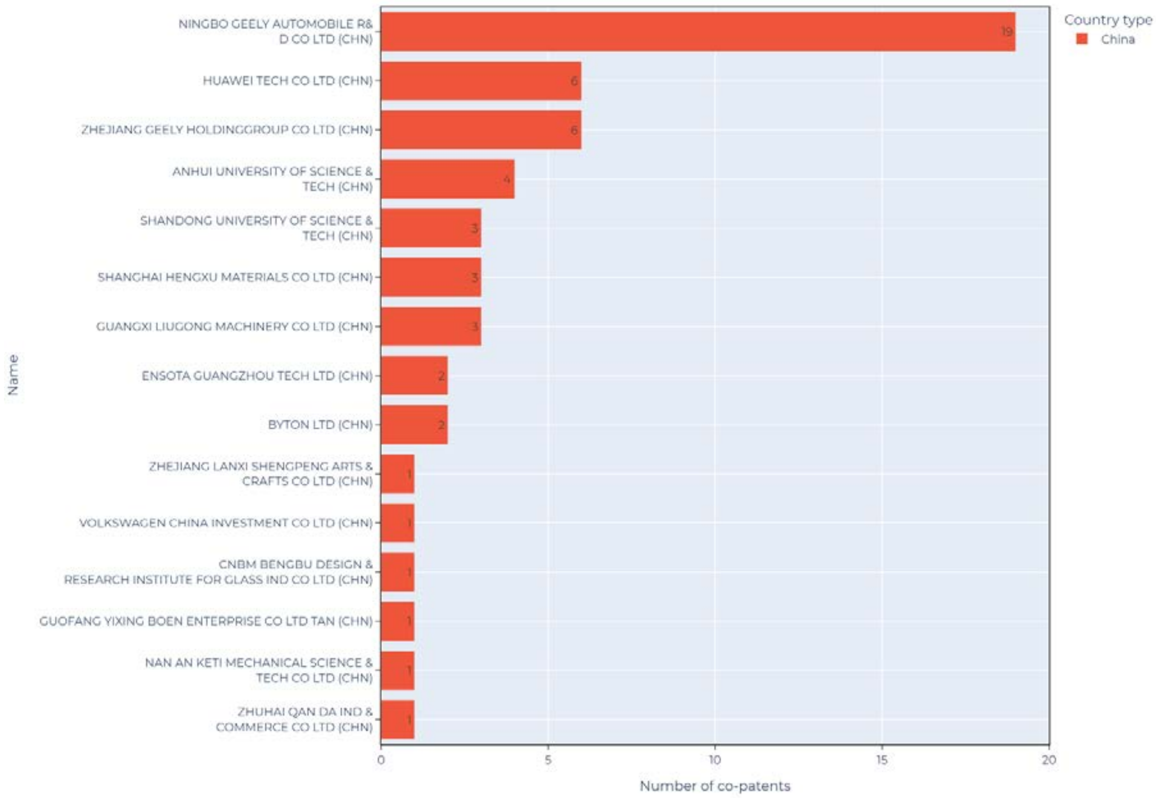


Figure 99. Top-15 Chinese applicants collaborating on co-patents in Fixed constructions with EU27/AC participants.

4.2.10 Engineering (F)

Engineering (full name of the section F: Mechanical Engineering; Lighting; Heating; Weapons; Blasting) focuses on machinery, engines, lighting devices, heating and cooling systems, as well as weaponry and explosive devices. In our data exploration, we found 753 co-patents tied to this technology section.

In Figure 100 WIPO, though still dominant, takes up a smaller portion with 47.8% of all applications in this sector. This is considerably lower than WIPO's share of 78.8% in all filed patents. Germany, with 22.4%, and EPO, with 14.9%, stand for more pronounced contributions in this section, compared to their representation in the dataset of overall patent filings.

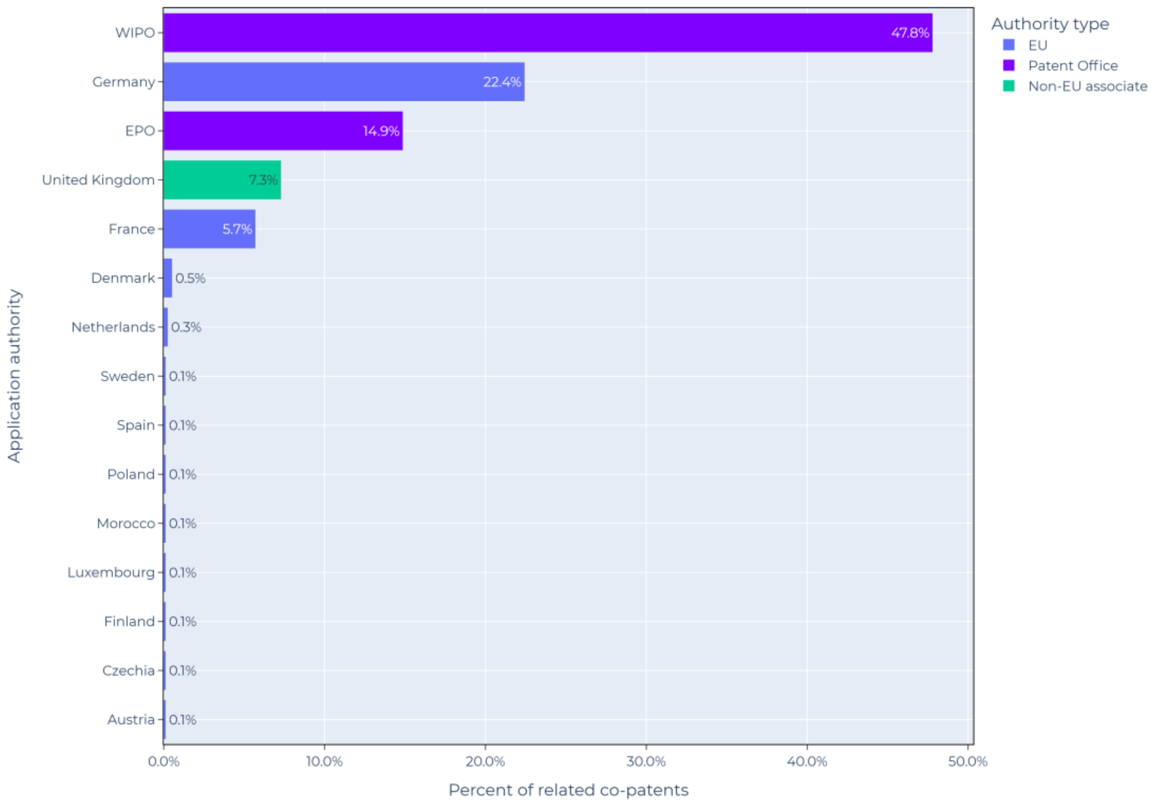


Figure 100. Percentage distribution of co-patents in Engineering by application authority.

The list of inventors (Figure 101) is led by China with a substantial share of 80.3%, echoing its dominant role in crafting innovations in this domain. Germany is also a significant contributor with 23.9%, followed by Sweden (12.9%) and a slightly increased contribution from France (8.5%) (*c.f.* Figure 69).

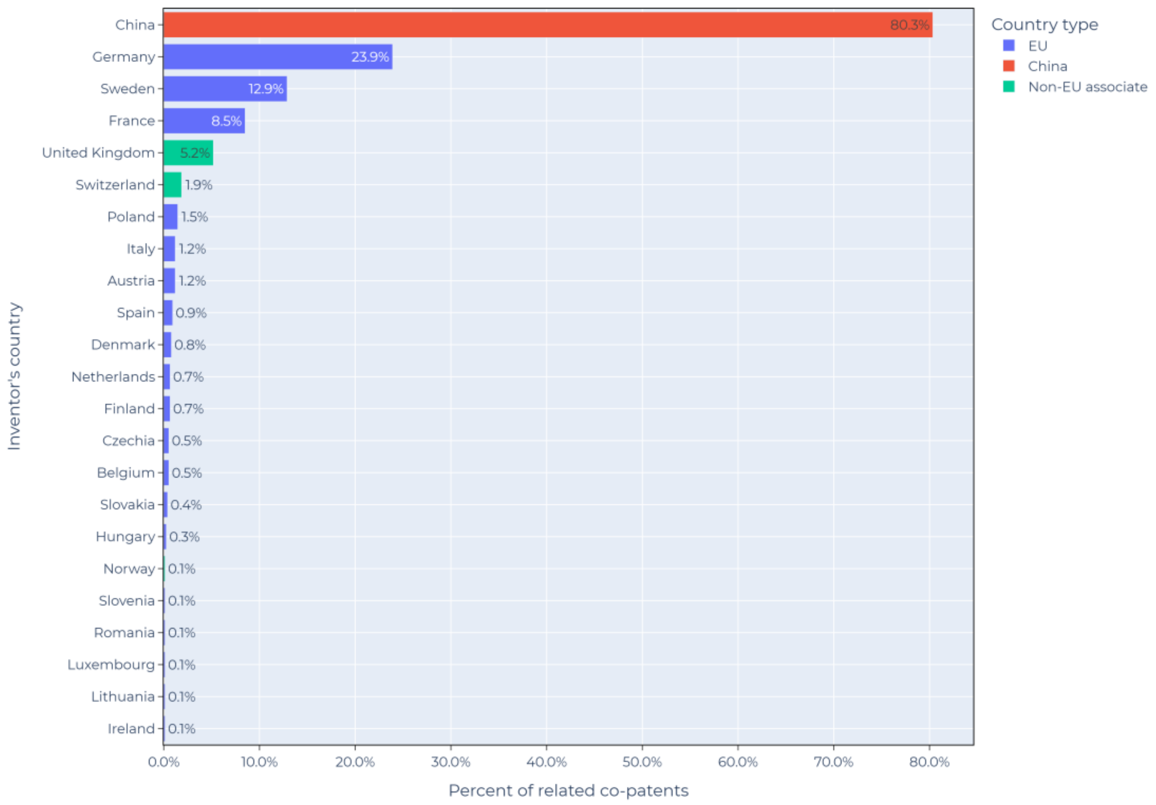


Figure 101. Percentage distribution of co-patents in Engineering by inventor country (with at least one applicant from the respective countries)

The distribution of applicants involves a few differences (Figure 102). While China remains at the forefront with 59.0%, Germany exhibits a significant presence in this section with 47.5%, emphasising its eminent role in mechanical engineering. The rate of Swiss ownerships is also higher than expected compared to overall numbers (11.0%).

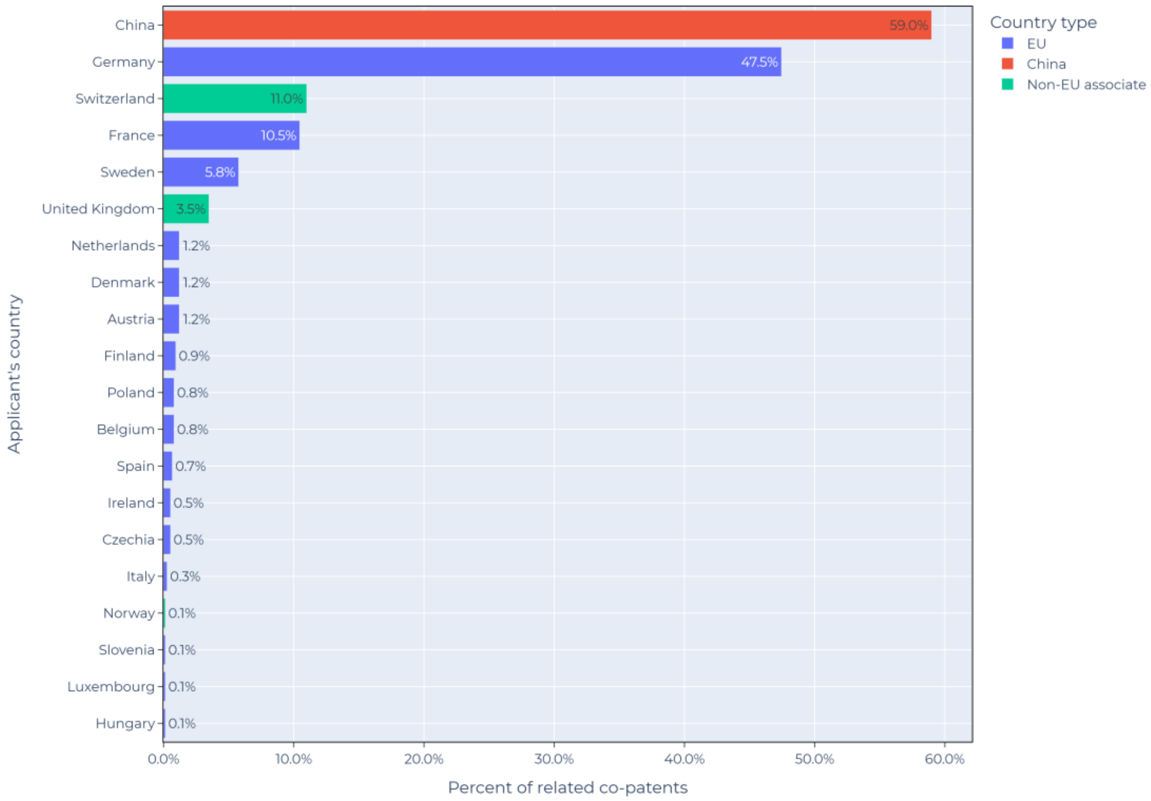


Figure 102. Percentage distribution of co-patents in Engineering by applicant country (with at least one applicant from the respective countries)

Overall, the results on leading companies from the EU27/AC (Figure 103) suggest a rich engineering heritage. Companies like SCHAEFFLER, BOSCH, and SIEMENS hint at a focus in co-patenting in the sectors of automotive components, automation technologies, and broad-based engineering solutions. AIR LIQUIDE (abbreviated name) stands for a dimension of gas technologies and services tailored for a myriad of industries. From the Chinese perspective (Figure 104), the spotlight remains on the automotive domain, with companies such as Geely hinting at an emphasis on automobile R&D. HUAWEI reinforces the technological dimension, underscoring the country's prowess in telecommunication solutions.

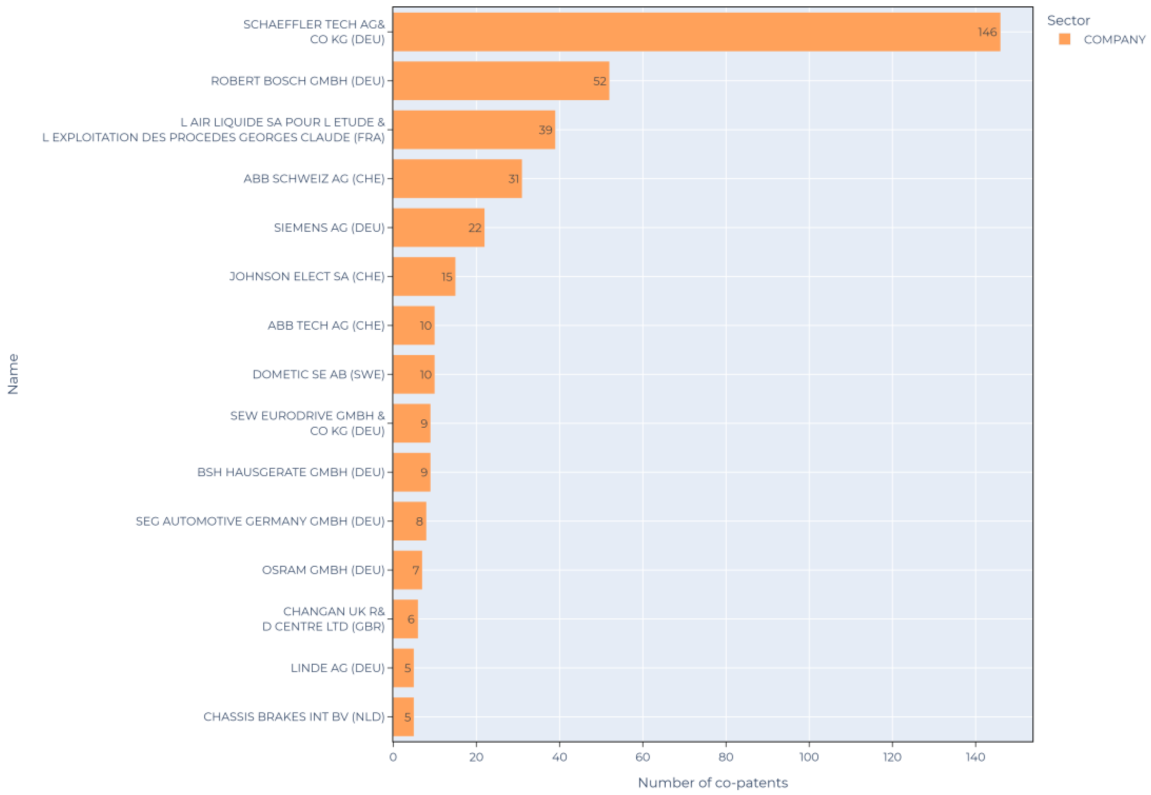


Figure 103. Top-15 EU27/AC applicants collaborating on co-patents in Engineering with Chinese participants.

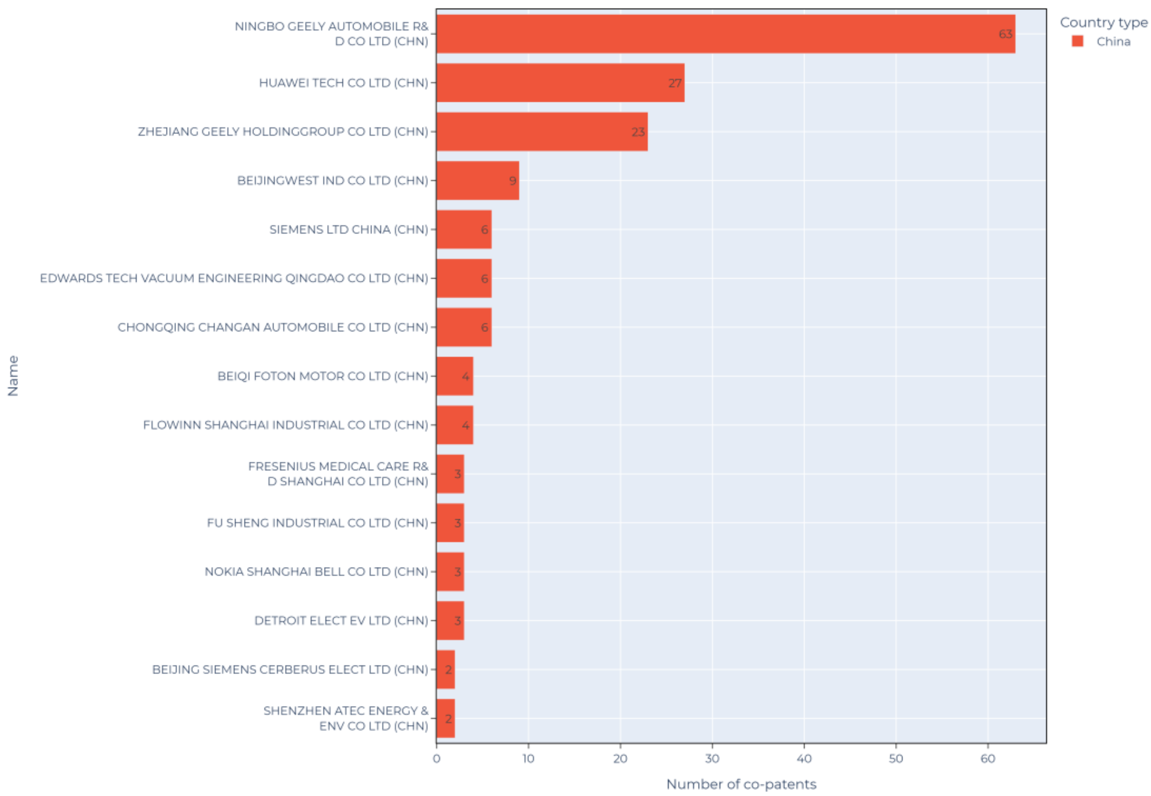


Figure 104. Top-15 Chinese applicants collaborating on co-patents in Engineering with EU27/AC participants.

4.2.11 Physics (G)

The IPC section of Physics addresses inventions in the realm of physics, including optics, electronics, computing, and measuring techniques. This IPC section contains the second most filings in our analysis, adding up to 2594 co-patents.

For application authorities (Figure 105), WIPO dominates the scene with 78.8% of all applications in Physics. This number is more or less consistent with WIPO's share in the overall dataset of co-patents. EPO and Germany contribute 10.6% and 4.4%, respectively, indicating a slight upward trend compared to the general distribution.

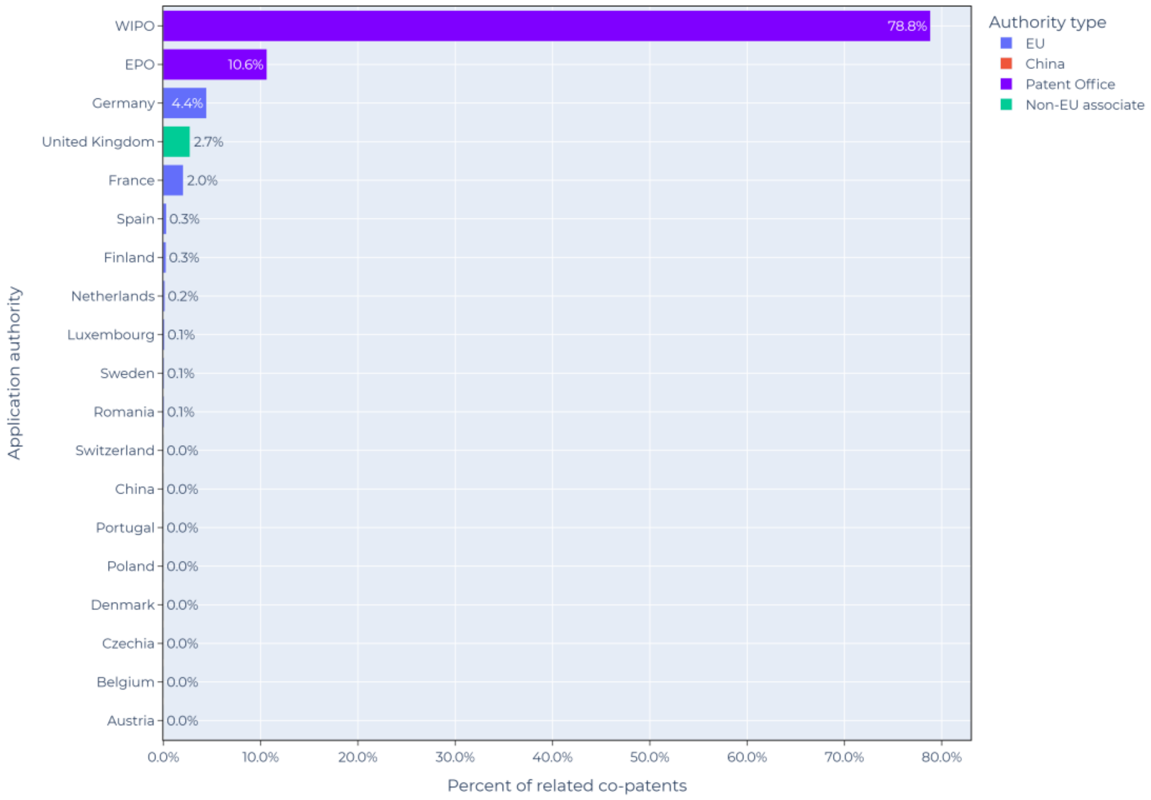


Figure 105. Percentage distribution of co-patents in Physics by application authority

Looking at contributors (Figure 106), China leads with 58.6%, which means a downward shift compared to Chinese contributors across all patent sections (71.2%) Germany and Sweden present stronger contributions with 34.9% and 12.9%, respectively.

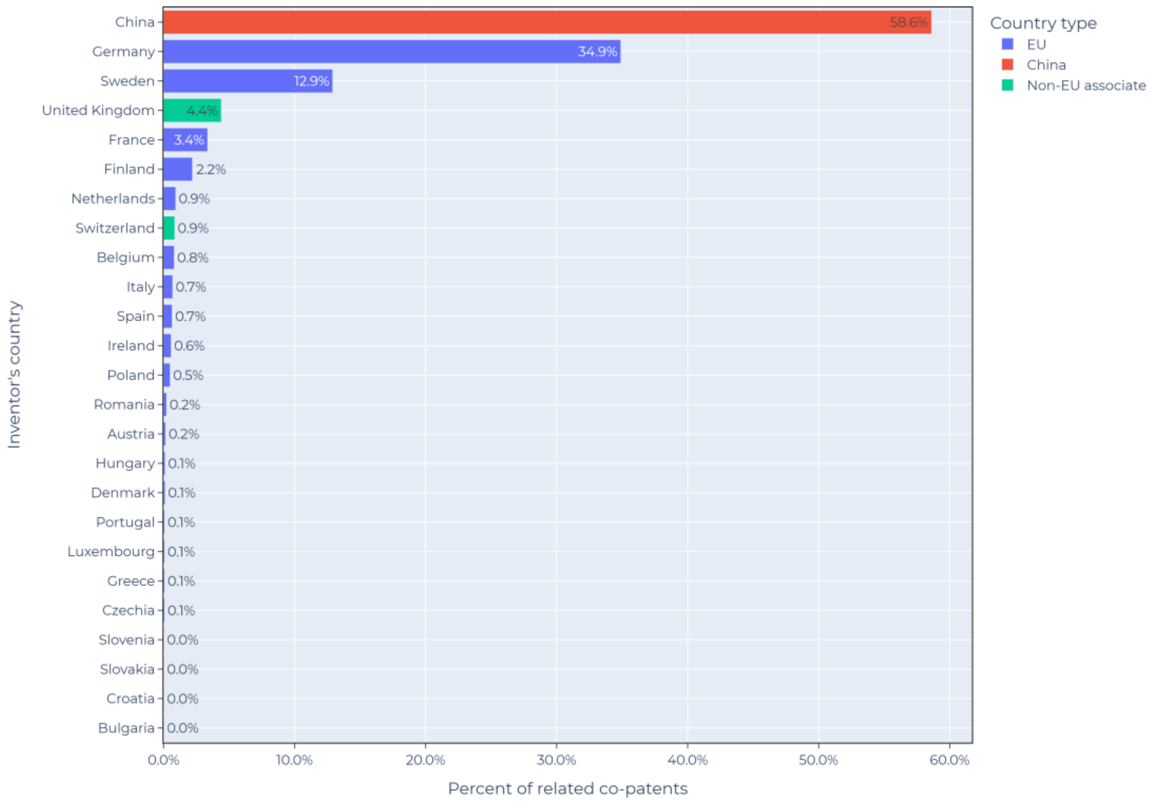


Figure 106. Percentage distribution of co-patents in Physics by inventor country (with at least one applicant from the respective countries)

In terms of applicant countries (Figure 107), China is at the helm too: 85.9% mean a considerable increase vis-à-vis its share of 57.5% in all patents. Germany, on the other hand, is seen participating significantly with 46.6%, emphasising its strong role in the physics domain.

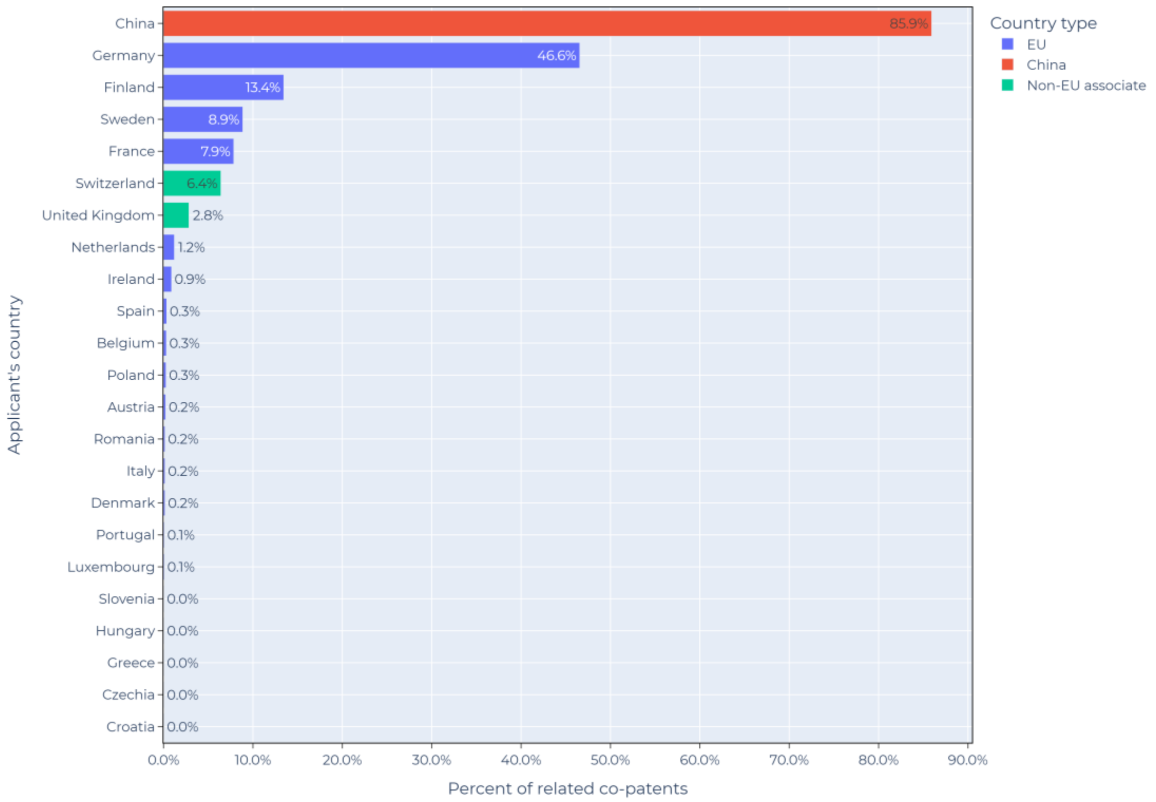


Figure 107. Percentage distribution of co-patents in Physics by applicant country (with at least one applicant from the respective countries)

Looking at the top-15 legal entities from the EU27/AC performing as applicants (Figure 108), the telecommunications sector again clearly shines through, with both Siemens and Nokia taking lead roles. Additionally, automation and electrical engineering remain key focus areas, as indicated by the presence of Siemens and ABB. On the Chinese spectrum (Figure 109), telecommunications remains pivotal, with Huawei and Nokia's daughter companies in China being prominent. Like with Engineering, the presence of Geely hints to the importance of automotive R&D in this collaboration.

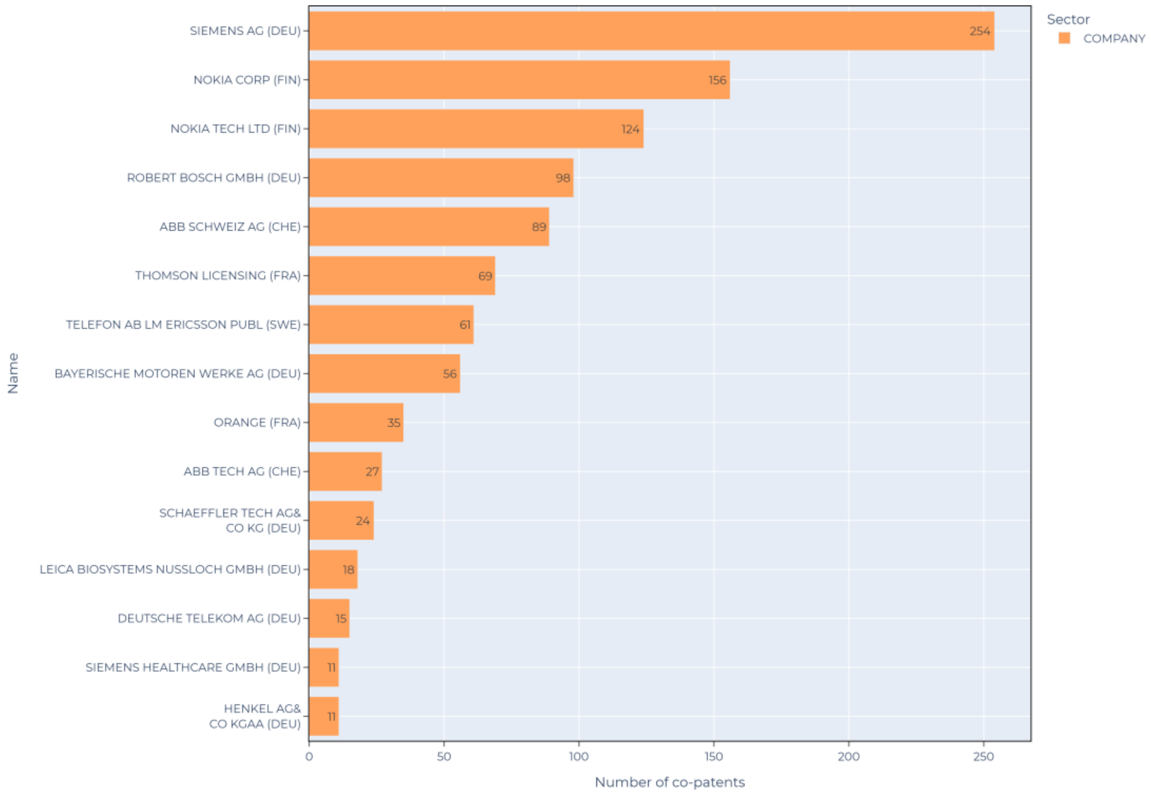


Figure 108. Top-15 EU27/AC applicants collaborating on co-patents in Physics with Chinese participants.

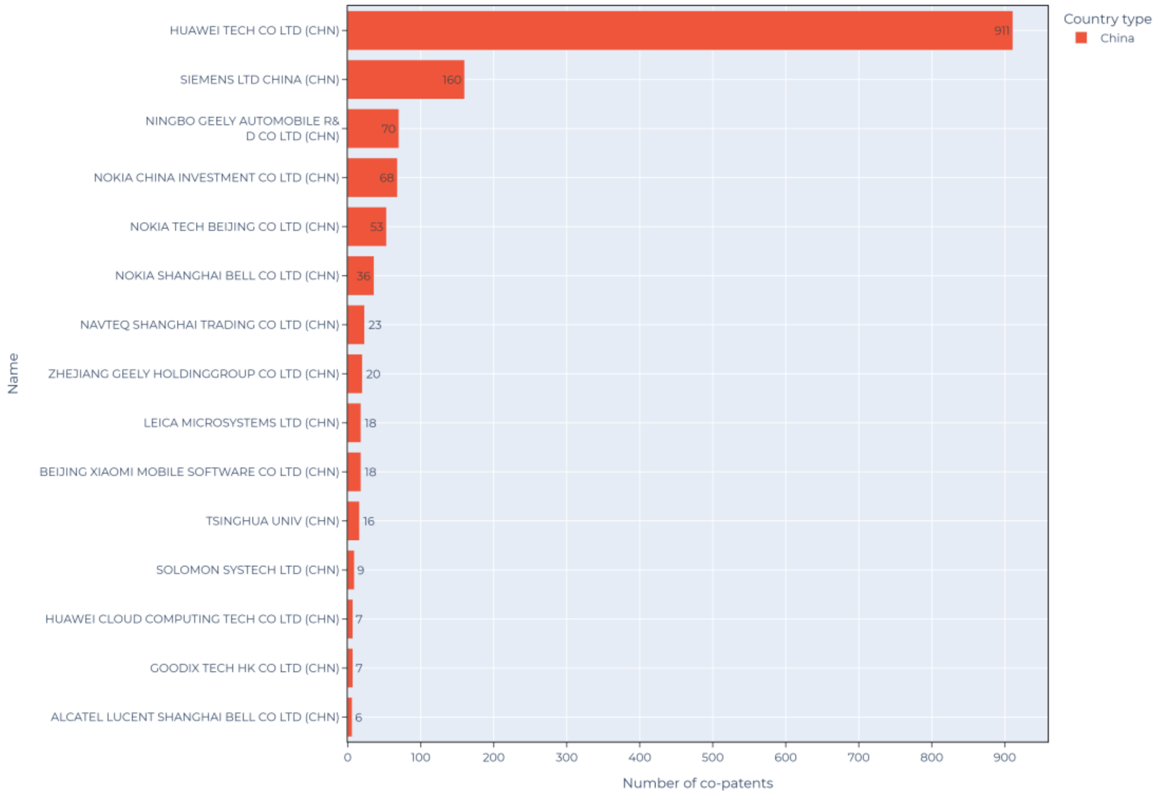


Figure 109. Top-15 Chinese applicants collaborating on co-patents in Physics with EU27/AC participants

4.2.12 Electricity (H)

Finally, the section of Electricity within the IPC standard covers electrical systems, devices, and methods, including circuitry, power generation, and communication technologies. It is the section with most patents found in our analysis (6738 in total).

Among application authorities (Figure 110), WIPO commands an overwhelming 88.6% of the applications, even surpassing its share of 78.8% as observed in the general dataset. EPO contributes 5.0%, which is somewhat smaller than its contributions generally, while Germany and the United Kingdom take up 2.5% and 2.6% respectively.

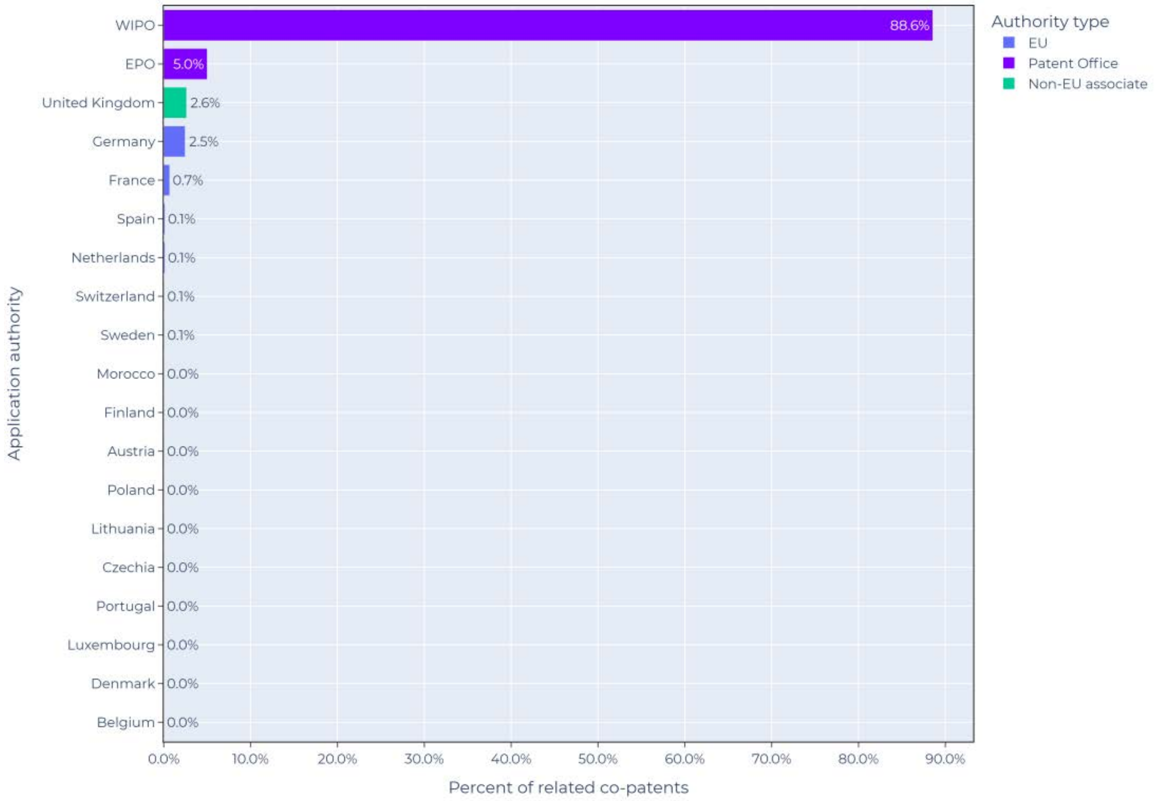


Figure 110. Percentage distribution of co-patents in Electricity by application authority

In the set of inventors (Figure 111), China holds a substantial 65.8%, which is a bit lower than its general 71.2% contribution across all sections. Germany shows a strong presence with 29.5%, while Sweden and Finland also make notable contributions with 16.4% and 9.6%, respectively.

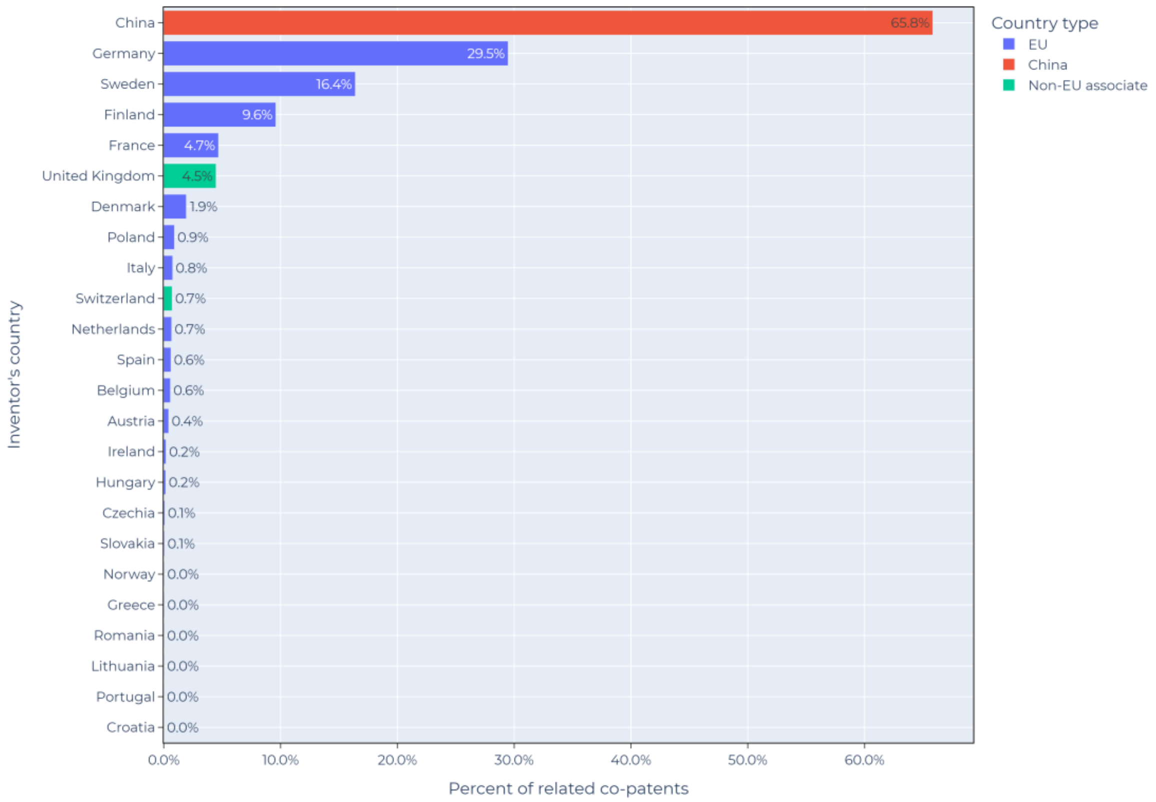


Figure 111. Percentage distribution of co-patents in Electricity by inventor country (with at least one applicant from the respective countries)

Among applicants (Figure 112), China's dominance in this section is evident with a staggering share of 90.5%. Sweden, Germany, and Finland are significant contributors as well, accounting for 26.4%, 25.5%, and 24.5% respectively. These numbers reflect Europe's strength in electricity-based innovations.

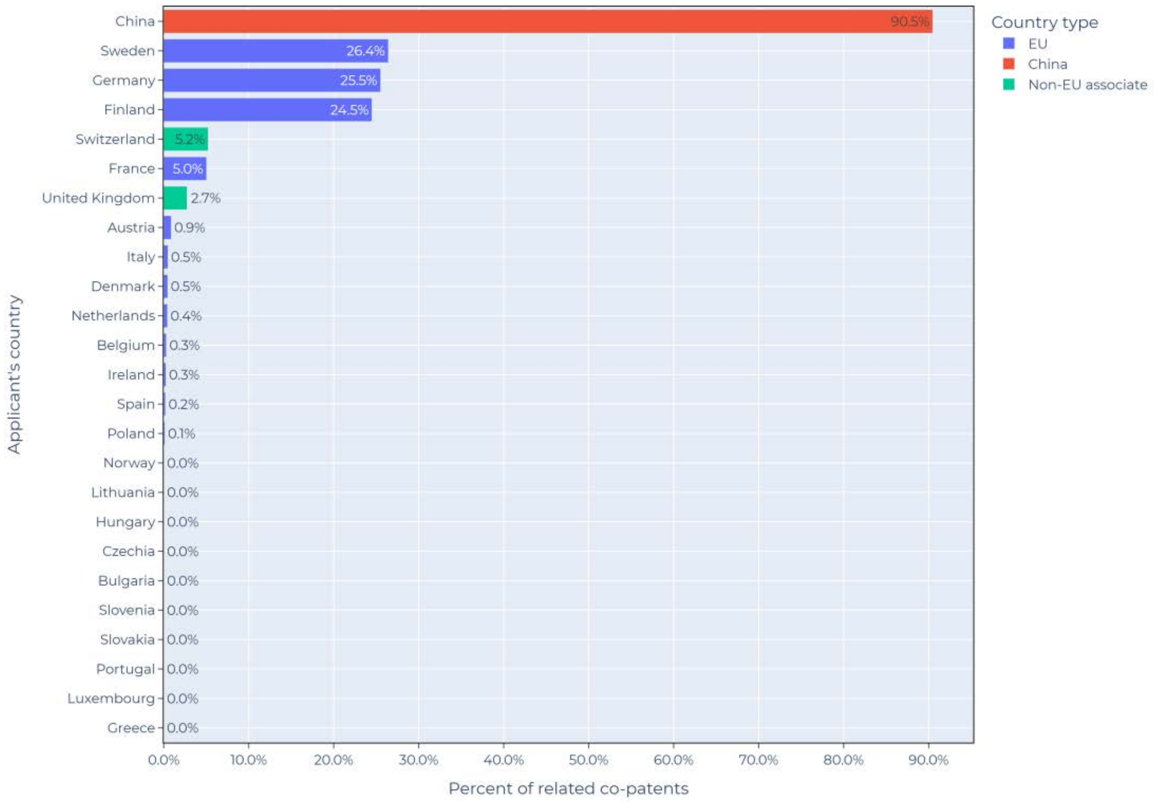


Figure 112. Percentage distribution of co-patents in Electricity by applicant country (with at least one applicant from the respective countries)

Finally, we are listing both the top-15 applicants from EU27/AC and from China within this sector. In the EU27/AC (Figure 113), telecommunications are at the helm, with Nokia and Ericsson taking the lead. Siemens and ABB bring to the table their strengths in electrical engineering, automation, and power technologies. In China (Figure 114), also telecommunications remains the central industry, but there's also a strong representation from the consumer electronics domain, with companies like Huawei and TCL.

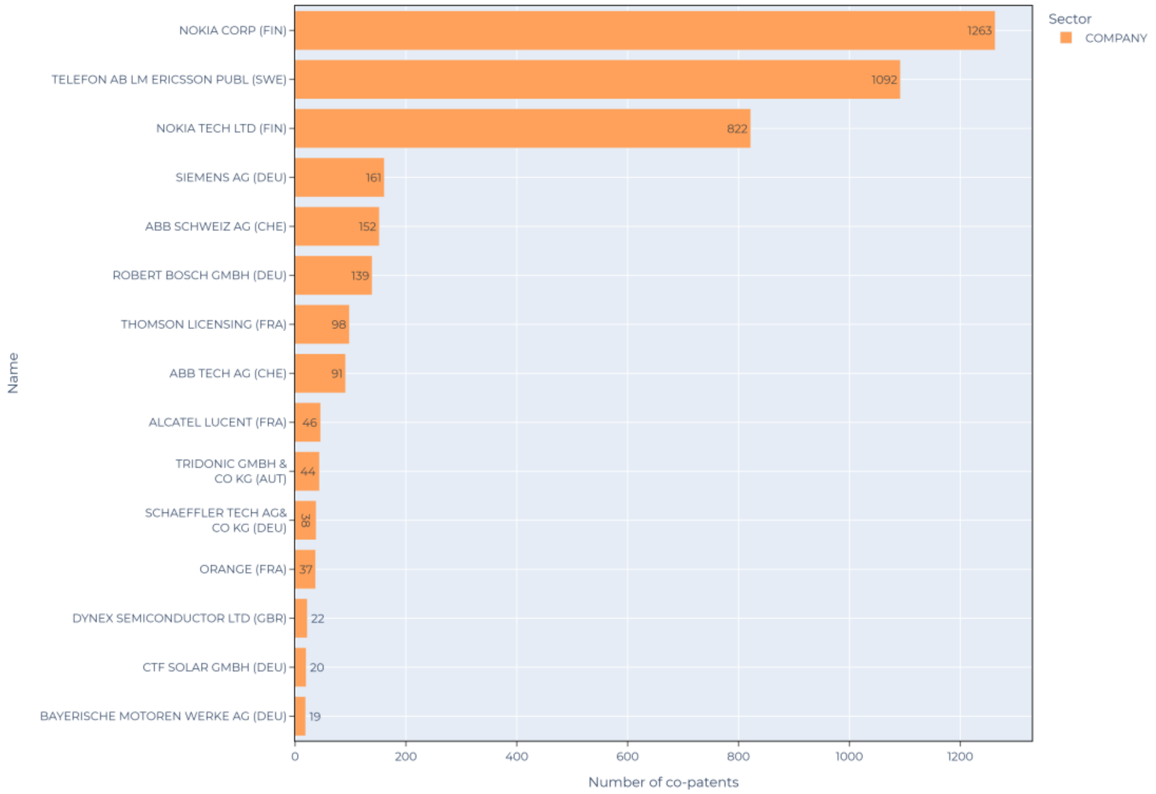


Figure 113. Top-15 EU27/AC applicants collaborating on co-patents in Electricity with Chinese participants

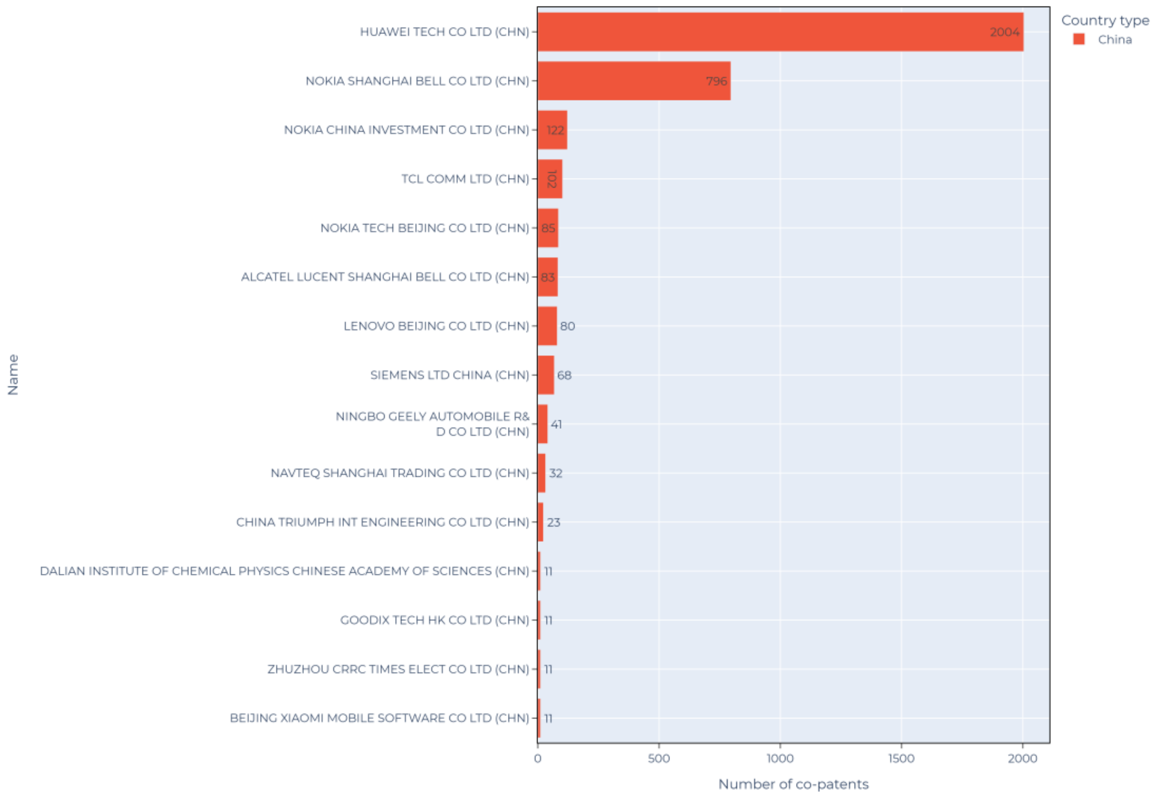


Figure 114. Top-15 Chinese applicants collaborating on co-patents in Electricity with EU27/AC participants.

5 CONCLUSIONS

This comprehensive bibliometric analysis of co-publication and co-patenting activities between China and the countries of the European Union (EU27) and Associated Countries (AC) in the domains of AI, machine learning, and big data provides several key insights.

Some of the key insights from the co-publication analysis are as follows:

- **China's Advancement in AI Research**: China has made remarkable progress in AI research, now on par with Western AI research. The increased collaboration with European institutions has further boosted China's research output and impact on the global AI landscape.
- **Intensive EU-China Collaboration**: EU-China research collaboration appears to be more intensive than US-China partnerships, making it a trending joint publication activity. The EU's strong scientific investment in AI, machine learning, and big data contributes to this trend.
- **Potential Dictation of AI-Oriented Research**: As China's AI research gains prominence, there are concerns about its potential influence on shaping AI-oriented research globally. Further research is needed to ascertain the extent and implications of this phenomenon.
- **Bias towards Applied Science Domains**: Our analysis indicates a strong bias towards applied science domains, such as fast application transformer networks, due to their short-term high returns in industry. This trend reflects the practical implications and commercial viability of AI/ML/Big Data research.
- **Temporal Trends**: Between 2015 and 2018, we observe a slight increase in co-publication output at the country level, indicating a growing interest in collaborative research during this period.
- **British Dominance in Research**: The British influence in joint publications is conspicuous, dominating research across multiple domains. However, this prevalence also makes it challenging to analyse the contributions of other EU27 institutions, prompting a focus shift towards individual EU countries.
- **Surprising Collaboration Patterns**: Notably, the Polish Academy of Sciences emerges as an active collaborator, particularly in strictly AI-related fields of journals. This finding suggests a dynamic and diverse research landscape within the European-Chinese collaboration.
- **Trending Fields**: Emerging fields, such as Nanotech, Distributed Computing, and Energy, are witnessing high collaboration activities, driven by their strategic importance. Similarly, AI/ML/Big Data-related domains, like Networking & Telecommunications, Industrial Automation, Image Processing, and Geological & Geomatics Engineering, also attract substantial research collaborations.
- **Dominant Collaborating Countries and Universities**: Certain scientific domains exhibit clear dominance of collaborating countries and universities. For example, the Karolinska Institute excels in Health Sciences, while Danish universities stand out in Energy and Electrical Engineering. The prominence of Finnish and Swedish universities are noteworthy in Networking & Telecommunications, especially since these countries can be regarded as the economic strongholds of field in Europe.
- **Weak Collaboration Patterns**: While EU27 institutions tend to collaborate more with the Chinese Academy of Sciences, the collaboration patterns of UK institutions appear more diverse, suggesting a potential focus on EU27 institutes by the Chinese Academy of Sciences.

- **Publishing Concerns in China**: There are concerns about the "publishing business" in China, where some researchers allegedly buy authorships of high-impact papers. This raises questions about research integrity and scholarly publishing practices in the country.

In conclusion, the analysis of co-publication activities between China and European countries in AI, machine learning, and big data showcases China's remarkable progress and its enthusiastic collaboration with European institutions. The EU-China partnership stands out as a significant and trending joint publication activity in the global AI research landscape. However, as China's influence on AI-oriented research grows, potential implications for the direction of AI research warrant close scrutiny. The strong bias towards applied science domains reflects the practical importance of AI/ML/Big Data research for industry and real-world applications.

The temporal trends reveal periods of increased collaboration, highlighting the dynamic nature of the relationship between China and European countries. The British dominance in research poses challenges for analysing the broader EU27 co-publication activity, necessitating a more focused examination. Surprising patterns in collaboration, especially the involvement of the Polish Academy of Sciences, showcase the diverse and evolving nature of research in this field. Trending fields gain popularity due to their strategic importance, while AI/ML/Big Data-related domains enjoy substantial activity due to their relevance in the technology landscape.

Dominant collaborating countries and universities underscore their expertise in specific domains, contributing significantly to joint research efforts. Despite certain weak collaboration patterns, the EU-China partnership remains robust and requires further examination. Lastly, concerns about the "publishing business" in China raise questions about research ethics and transparency, necessitating vigilant monitoring of scholarly practices.

Some of the key insights from the co-patent analysis are as follows:

- **Data Integrity & Bias**: The PATSTAT dataset presents certain data quality challenges, notably due to time-lag issues. Variations in patent authority policies across countries introduce biases, especially concerning the country of origin for applicants and inventors. Country-specific policies can skew data interpretations.
- **Evolution of Innovation Flow**: Historically, Europe held a significant edge in innovative outputs, especially in terms of ownership-bias. However, recent trends indicate that China has rapidly caught up, now showcasing an innovation flow that is comparable to Europe's. Note however, that this is somewhat related to complex corporate structures, and affiliated firms.
- **Complex Corporate Structures**: Global companies often have intricate structures with numerous subsidiaries. This complexity can obfuscate the true origin or hierarchy of patent applicants, making it essential to have expertise when interpreting the data, especially for multinational corporations.
- **Domain Emphasis**: There is a pronounced focus on certain sectors across the co-patenting landscape, notably:
    - Telecommunications & Electronics: With giants like Nokia, Ericsson, and Huawei frequently emerging as top applicants.
    - Chemical & Material Sciences: Indicative of advancements in chemical processes, materials, and pharmaceuticals.
    - Automotive & Automation: Highlighted by the presence of entities like Geely and Siemens.

    - Medical Diagnostics: Evident from the various patents related to health sciences and innovations.
- **Preference for International Patent Offices**: International patent offices, especially WIPO, are favored for co-patenting activities. This underscores the global nature of the collaborations and the desire for broad intellectual property protection.
- **Telecom and Electronics Supremacy**: Both China and EU27/AC nations display a significant emphasis on the telecommunications and electronics sectors, reflecting the global importance and rapid advancements in these domains.
- **Varied Landscape of Collaboration**: Different countries often take the lead in specific sectors, suggesting the inherent strengths, specialisations, and strategic focuses of each nation. While China often dominates in terms of inventorship, countries like Germany, Sweden, and Finland also showcase significant contributions across various sectors.

Over recent decades, China has witnessed an impressive transformation in its patent filing landscape, a shift catalysed by the government's pronounced emphasis on innovation and its comprehensive intellectual property (IP) reforms (Liu, 2011). As part of this initiative, the government has strategically incentivised domestic patent filings through a plethora of measures including financial rewards, tax breaks, and preferential policies. Such measures have significantly contributed to the country's meteoric rise in patent filings (Eberhardt et al., 2016). Moreover, as China positions itself on the global innovation stage, inventors and corporations within its borders are increasingly directing their patent filings to influential international markets, especially the U.S. and key institutions like the WIPO (WIPO, 2017). This strategic move not only underscores China's intent to secure its innovations in pivotal global arenas but also emphasises its pursuit of recognition and legitimacy for its technological prowess.

However, the vast landscape of patent filings in China is not without its challenges. Critiques have surfaced regarding the rigor of the patent examination process. Some sectors of the academic and industry spheres posit that the staggering volume of patent submissions might overshadow the essence of genuine innovation. Concerns have arisen regarding the quality, especially when juxtaposed with patents from regions like the U.S. or Europe. The dominance of "utility model" patents, which often mandate a lower inventiveness standard and undergo minimal examination, accentuates these concerns (Love et al., 2017). Historically, China's IP enforcement mechanisms have been under the scanner for perceived laxity. Yet, recent times have witnessed concerted endeavors to bolster IP rights protection. This strengthening is evident in the rising trend of domestic firms leveraging the patent system for litigation against both local and international adversaries (Liu, 2019).

In conclusion, China's patent landscape mirrors its ambitions, challenges, and the multifaceted nature of its innovation ecosystem. As the country continues its trajectory towards becoming an IP powerhouse, it grapples with the intricate balance between quantity and quality, local and global outreach, and the interplay between state and private entities.

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7 ANNEX

Annex Table 1. Complete list of keyword tokens incorporated in the Web of Science search query.

Keyword token	Note
"neural network*"	
"machine* learn*"	
"deep learn*"	
"clustering"	
"remote sensing"	
"convolutional neural"	
"Internet of Things"	
"feature extraction"	
"genetic algorithm*"	
"big data*"	
"artificial intelligence*"	
"data driven*"	
"support vector machine*"	
"classifier"	
"logistic regression" NOT "p="	To exclude studies relying on statistical analyses
"optimization algorithm*"	
"principal component analysis"	
"artificial neural network*"	
"swarm optimization"	
"regularization"	
"linear regression" NOT "p="	To exclude studies relying on statistical analyses
"optimization algorithm"	
"random forest"	
"cloud computing"	
"reinforcement learning"	
"computer vision"	

"kalman filter*"	
"image processing"	
"data mining"	
"evolutionary algorithm*"	
"edge computing"	
"*supervised learning"	
"computational modeling"	
"pattern recognition"	
"image classification"	
"long short-term memor*"	
"robotics"	
"image segmentation"	
"convex optimization"	
"covariance matri*"	
"attention mechanism*"	
"markov chain"	
"object detection" NOT "brain"	To exclude psychological/neurological studies
"clustering algorithm*"	
"recurrent neural network*"	
"data augmentation"	
"transfer learning"	
"loss function*"	
"adversarial network*"	
"decision tree*"	
"multi agent system*"	
"fuzzy set*"	
"convolutional network*"	
"image reconstruction"	
"data* analytic*"	
"smart grid"	

"autoencoder*"	
"fuzzy logic"	
"radial basis function"	
"Bayesian network*"	
"dimensionality reduction"	
"face recognition" NOT "brain"	To exclude psychological/neurological studies
"gaussian process"	
"anomaly detection"	
"k-nearest neighbor*"	
"natural language processing"	
"monte carlo method"	
"large$ dataset*"	
"gradient descent"	
"support vector regression"	
"extreme learning machine*"	
"perceptron*"	
"model selection"	
"ensemble learning"	
"representation learning"	
"recommender system*"	
"target tracking"	
"singular value decomposition"	
"KNN"	
"feature learning"	
"smart city"	
"sentiment analy*"	
"markov decision process"	
"k-means clustering"	
"independent component analysis"	
"brain computer interface"	

"human-computer interaction"	
"markov chain monte carlo"	
"hierarchical clustering"	
"semantic web*"	
"semi-supervised learning"	
"human-robot interact*"	
"knowledge graph*"	
"speech recognition" NOT "brain"	
"ensemble model*"	
"fog computing"	
"map$reduce"	
"evolutionary computation*"	
"data science*"	
"text mining"	
"generative model*"	
"active learning"	
"swarm intelligence"	
"multi-task learning"	
"language model*"	
"collaborative filtering"	
"backpropagation"	
"machine vision"	
"computer-aided diagnosis"	
"gated recurrent unit*"	
"lagrange multiplier"	
"expert system*"	
"learning rate*"	
"hadoop*"	
"markov process"	
"nonlinear optimization"	

"learning system"	
"self-organizing map*"	
"smart manufacturing"	
"smart home"	
"few shot learning"	
"few-shot learning"	
"meta-learning"	
"meta learning"	
"adversarial training"	
"zero-shot learning"	
"word embedding*"	
"expectation maximization algorithm*"	
"stochastic gradient descent"	
"ridge regression"	
"deep belief network*"	
"non-negative matrix factorization"	
"affective computing"	
"latent dirichlet allocation"	
"kernel method"	
"kernel learning"	
"feature engineering"	
"variational inference"	
"image representation"	
"manifold learning"	
"t5"	
"adversarial example*"	
"knowledge distillation"	
"time series forecast*"	
"variational autoencoder*"	
"lasso regression"	

"smart energy"	
"dbscan"	
"multi-label classification"	
"intelligent robot*"	
"ubiquitous computing"	
"gaussian mixture models"	
"smart technolog*"	
"boltzmann machine*"	
"smart buildings"	
"predictive analytic*"	
"pervasive computing"	
"smart agriculture"	
"capsule network*"	
"human-in-the-loop"	
"intelligent agent*"	
"ai applications"	
"word vector*"	
"transformer model*"	
"facial recognition"	
"unstructured data*"	
"restricted boltzmann machine*"	
"albert"	
"lifelong learning"	
"autonomous agents"	
"chatbot*"	
"Cholesky decomposition"	
"no$sql"	
"nosql"	
"explainable AI"	
"seq2seq"	

"probabilistic graphical model*"	
"QR decomposition"	
"L? regulari*"	
"unsupervised deep learning"	
"data warehouse*"	
"quantum machine learning"	
"continual learning"	
"smart environment"	
"multimodal learning"	
"smart health"	
"artificial immune system*"	
"swarm robotics"	
"kernel machine*"	
"latent factor model*"	
"eigendecomposition"	
"adversarial machine"	
"adversarial machine learning"	
"smart mobility"	
"sequence-to-sequence model*"	
"eigen decomposition"	
"adversarial robustness"	
"smart parking"	
"adversarial neural"	
"roberta"	
"bidirectional encoder representations from transformer*"	
"locally linear embedding*"	
"Hebbian learning"	
"one-shot learning"	
"multimodal representation"	
"smart tourism"	

"entity extraction"	
"adaptive moment estimation"	
"ontology learning"	
"topic modeling*"	

Annex Query 1. Complete Web of Science query used on the search interface

CU=(PEOPLES R CHINA OR HONG KONG) AND CU=(AUSTRIA OR BELGIUM OR BULGARIA OR CROATIA OR CYPRUS OR CZECH REPUBLIC OR DENMARK OR ESTONIA OR FINLAND OR FRANCE OR GERMANY OR GREECE OR HUNGARY OR IRELAND OR ITALY OR LATVIA OR LITHUANIA OR LUXEMBOURG OR MALTA OR NETHERLANDS OR POLAND OR PORTUGAL OR ROMANIA OR SLOVAKIA OR SLOVENIA OR SPAIN OR SWEDEN OR NORWAY OR SWITZERLAND OR UNITED KINGDOM OR ENGLAND OR WALES OR SCOTLAND OR N IRELAND) AND TS=("neural network*" OR "machine* learn*" OR "deep learn*" OR "clustering" OR "remote sensing" OR "convolutional neural" OR "Internet of Things" OR "feature extraction" OR "genetic algorithm*" OR "big data*" OR "artificial intelligence*" OR "data driven*" OR "support vector machine*" OR "classifier" OR ("logistic regression" NOT ("p" NEAR/0 "0.0*" OR "p$value*" OR "p-value*")) OR "optimization algorithm*" OR "principal component analysis" OR "artificial neural network*" OR "swarm optimization" OR "regularization" OR ("linear regression" NOT ("p" NEAR/0 "0.0*" OR "p$value*" OR "p-value*")) OR "optimization algorithm" OR "random forest" OR "cloud computing" OR "reinforcement learning" OR "computer vision" OR "kalman filter*" OR "image processing" OR "data mining" OR "evolutionary algorithm*" OR "edge computing" OR "*supervised learning" OR "computational modeling" OR "pattern recognition" OR "image classification" OR "long short-term memor*" OR "robotics" OR "image segmentation" OR "convex optimization" OR "covariance matri*" OR "attention mechanism*" OR "markov chain" OR ("object detection" NOT "brain") OR "clustering algorithm*" OR "recurrent neural network*" OR "data augmentation" OR "transfer learning" OR "loss function*" OR "adversarial network*" OR "decision tree*" OR "multi agent system*" OR "fuzzy set*" OR "convolutional network*" OR "image reconstruction" OR "data* analytic*" OR "smart grid" OR "autoencoder*" OR "fuzzy logic" OR "radial basis function" OR "Bayesian network*" OR "dimensionality reduction" OR ("face recognition" NOT "brain") OR "gaussian process" OR "anomaly detection" OR "k-nearest neighbor*" OR "natural language processing" OR "monte carlo method" OR "large$ dataset*" OR "gradient descent" OR "support vector regression" OR "extreme learning machine*" OR "perceptron*" OR "model selection" OR "ensemble learning" OR "representation learning" OR "recommender system*" OR "target tracking" OR "singular value decomposition" OR "KNN" OR "feature learning" OR "smart city" OR "sentiment analy*" OR "markov decision process" OR "k-means clustering" OR "independent component analysis" OR "brain computer interface" OR "human-computer interaction" OR "markov chain monte carlo" OR "hierarchical clustering" OR "semantic web*" OR "semi-supervised learning" OR "human-robot interact*" OR "knowledge graph*" OR ("speech recognition" NOT "brain") OR "ensemble model*" OR "fog computing" OR "map$reduce" OR "evolutionary computation*" OR "data science*" OR "text mining" OR "generative model*" OR "active learning" OR "swarm intelligence" OR "multi-task learning" OR "language model*" OR "collaborative filtering" OR "backpropagation" OR "machine vision" OR "computer-aided diagnosis" OR "gated recurrent unit*" OR "lagrange multiplier" OR "expert system*" OR "learning rate*" OR "hadoop*" OR "markov process" OR "nonlinear optimization" OR "learning system" OR "self-organizing map*" OR "smart manufacturing" OR "smart home" OR "few shot learning" OR "few-shot learning" OR "meta-learning" OR "meta learning" OR "adversarial training" OR "zero-shot learning" OR "word embedding*" OR "expectation maximization algorithm*" OR "stochastic gradient descent" OR "ridge regression" OR "deep belief network*" OR "non-negative matrix factorization" OR "affective computing" OR "latent dirichlet allocation" OR "kernel method" OR "kernel learning" OR "feature engineering" OR "variational inference" OR "image representation" OR "manifold learning" OR "t5" OR "adversarial example*" OR "knowledge distillation" OR "time series forecast*" OR "variational autoencoder*" OR "lasso regression" OR "smart energy" OR "dbscan" OR "multi-label classification" OR "intelligent robot*" OR "ubiquitous computing" OR "gaussian mixture models" OR "smart technolog*" OR "boltzmann machine*" OR "smart buildings" OR "predictive analytic*" OR "pervasive computing" OR "smart agriculture" OR "capsule network*" OR "human-in-the-loop" OR "intelligent agent*" OR "ai applications" OR "word vector*" OR "transformer model*" OR "facial recognition" OR "unstructured data*" OR "restricted boltzmann machine*" OR "albert" OR "lifelong learning" OR "autonomous agents" OR "chatbot*" OR "Cholesky decomposition" OR "no$sql" OR "nosql" OR "explainable AI" OR "seq2seq" OR "probabilistic graphical model*" OR "QR decomposition" OR "L? regulari*" OR "unsupervised deep learning" OR "data warehouse*" OR "quantum machine learning" OR "continual learning" OR "smart environment" OR "multimodal learning" OR "smart health" OR "artificial immune system*" OR "swarm robotics" OR "kernel machine*" OR "latent factor model*" OR "eigendecomposition" OR "adversarial machine" OR "adversarial machine learning" OR "smart mobility" OR "sequence-to-sequence model*" OR "eigen decomposition" OR "adversarial robustness" OR "smart parking" OR "adversarial neural" OR "roberta" OR "bidirectional encoder representations from transformer*" OR "locally linear embedding*" OR "Hebbian learning" OR "one-shot learning" OR "multimodal representation" OR "smart tourism" OR "entity extraction" OR "adaptive moment estimation" OR "ontology learning" OR "topic modeling*") AND PY=(2011-2022)